AN ASSESSMENT OF MODERN METHODS FOR ROTOR TRACK AND BALANCE

THESIS

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AFIT/GAE/ENY/04-J11

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Abstract

One routine maintenance item facing the helicopter industry today is the issue of rotor track and balance (RT&B). While the task of reducing vibrations is often overlooked as simply an unimportant "maintenance" concern, what should not be overlooked is the extensive amount of time and money committed by maintenance to smoothing an aircraft.

If there were a way to make the process of rotor track and balance more efficient it would be a huge boost to the helicopter industry in both time and money. The first steps towards research into new and improved methods is to evaluate what is currently used in the field, determine if there is room for improvement and if so what can be improved.

While each company may use a slightly different approach to correct the problem, each method has essentially the same objective— to reduce vibrations in the helicopter structure due to main and tail rotor rotation.

This document reflects the findings of a study done to gather information and evaluate the different RT&B methods that currently exist, pinpointing the existing weaknesses in the process. In most all cases, a qualitative approach was used in determining problems and comparing current systems as the actual proprietary algorithms used by RT&B companies were unavailable.

Acknowledgements

I would like to acknowledge my advisor, Dr. Kunz for his help in the thesis process and the U.S. Army Aviation & Missile Command, Aviation Engineering Directorate, Aeromechanics Division (AMSAM-RD-AE-A), Redstone Arsenal, AL for their contributions to this document, especially Dr. Jon Keller and Mr. Eric Bale. I would also like to thank Dr. Mark Hollins of Naval Air Warfare Center Aviation Division (NAWCAD), Patuxent River NAS, MD for his contributions to this document.

Michael J. Renzi

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<u>Acronyms</u>

AMRDEC	Aviation Missile Research Development and Engineering Center
ATABS	Automated Track and Balance Sets
AVA	Aviation Vibration Analyzer
Cpm	Cycles per minute
DSS	Dynamic Solutions Systems
HUMS	Health Usage and Monitoring System
IMD	Integrated Mechanical Diagnostics
ips	inches/sec
NAWCAD	Naval Air Warfare Center Aircraft Division
rpm	revolutions per minute
RT&B	Rotor Track and Balance
THUMS	Total Usage and Monitoring System
VATS	Vibration Analysis Test Sets
VMEP	Vibration Management Enhancement Program

AN ASSESSMENT OF MODERN METHODS FOR ROTOR TRACK AND BALANCE

I. Introduction

1.1 General

Helicopter rotor track and balance (RT&B) is currently a major high-cost maintenance item in today's fleet of helicopters. Smoothing vibrations in today's helicopters involves an extensive amount of maintenance man-hours and aircraft flight hours. [Keller, 2004] High maintenance time eats away at the life-cycle usefulness of the aircraft, burns high cost fuel, and detracts from the operational readiness of the aircraft. For these reasons, the most efficient method possible of smoothing main and tail rotor vibrations should be used to reduce all the costs of this necessary task.

1.2 Problem Statement

What are the current methods used to smooth helicopter vibrations induced from the main and tail rotors? Which method is most efficient? What are the biggest areas of improvement that can be made in today's popular techniques for smoothing helicopter vibrations?

1.3 Objectives

The objective of this research is to determine what methods currently exist for helicopter rotor track and balance, and pinpoint weaknesses and suggest areas that need improvement.

1.4 Research Methods

There is very little written material on the subject of helicopter rotor track and balance. Therefore, research required TDY trips to Aviation Missile Research Development and Engineering Center (AMRDEC) at Redstone Arsenal, AL , Naval Air Warfare Center Aircraft Division (NAWCAD) at Patuxent River NAS, MD, and a trip to the U.S. Army National Guard Unit in Akron, OH. Additionally, phone interviews were conducted with representatives in the field of RT&B. Incidentally, all photos in this document, unless otherwise noted, were taken on one of the TDY trips mentioned above.

1.5 Chapter Summary

Helicopter rotor track and balance is a major maintenance cost of today's helicopter fleets. For this reason, the most efficient method of smoothing should be employed to save on the high cost of man-hours, fuel, aircraft flight hours, and aircraft unavailability. This document will report on the major players in the RT&B market and point out areas that could use improvement.

II. Background

2.1 Introduction

Before specific discussion of how rotor track and balance is performed, a more general background is necessary on the basics of rotor track and balance and why it is necessary

2.2 Defining Track and Balance

What exactly do we mean by rotor track and balance? Historically, the term “track” refers to the actual vertical location of each blade tip while the rotor is spinning. When the tips of each blade are all passing through the same plane, the helicopter is said to have a perfect track. The term “balance” refers to both the mass balance and the aerodynamic balance of the rotor. The problem is more complex than say balancing a wheel/tire on an automobile because the rotor and blade assembly has inherent aerodynamics that must be considered as well. The terms “track” and “balance” aren’t necessarily the best terms to describe this maintenance process. The real objective of RT&B is to smooth the aircraft by reducing vibrations created by the rotating main and tail rotors. Whether or not the aircraft rotor blades are in perfect “track” is really not important (as pioneers once thought) if the aircraft structure is vibration free. Helicopter rotor smoothing is a more generic term which better suits the process but the term “rotor track and balance” is the industry term for the process. [Johnson, History].

2.3 Aircraft Harmonics

A helicopter is a complex machine of systems and subsystems, many of which are rotating or moving in some way. Among the rotating components are the main and tail

rotors. The two rotors are responsible for the majority of the violent vibrations felt in a typical helicopter. This discussion will be limited to the main rotor.

Inherent to the spinning rotors are different types of vibration and different vibration frequencies. The main rotor produces both vertical and lateral type vibrations. Vertical vibrations are most commonly the result of aerodynamic differences between the blades resulting in asymmetrical lift characteristics. The most common reason for a lateral vibration is a mass imbalance somewhere in the rotor assembly. Again, asymmetries are the typical cause for this. Another reason for lateral vibration is two or more blades out of vertical balance causing a rolling motion in the helicopter.

The main rotor head has several inherent vibration frequencies associated with its rotation. The largest amplitude of vibration due to the main rotor occurs at a frequency equal to the rotating speed of the rotor. RT&B is designed to smooth this "1-per-rev" frequency of vibration from the spinning rotor. Vibrations at higher frequencies, namely n-per-rev frequencies, are inherent in the spinning rotor. While some companies claim to also be able to smooth the higher harmonics with their equipment, the reality is that only the 1-per-rev can be directly adjusted. Any other improvements are an indirect result of the 1-per-rev adjustment. [Robinson, 1]

2.4 Brief History

The process of RT&B, like anything else, has evolved over the years, as technology has improved and new ideas have been tested.

2.4.1 Rotor Tracking History

Over the past few decades, several methods of rotor tracking have been employed. The first method used was flag tracking. In this case, the tip of each blade is marked with a different colored chalk or grease pencil and allowed to pass by a white rag or “flag” mounted to a long, lightweight, vertical pole. With the helicopter on the ground, the flag was moved slowly toward the rotor disk until contact was made with the blade tips. The relative path of each blade could be seen on the rag and then appropriate adjustments could be made to correct for these “track splits.” This method was dangerous and did not allow for track measurements off the ground. [Robinson, 2]

The next track method employed was called electro-optical tracking. Developed in the 1960s by *Chicago Aerial*, this method relied on opto-electronics to determine rotor track. A photographic image of each blade tip is captured by the tracker during a revolution and compared to determine relative track of each blade. [Johnson, History]

Then, in the late 60's/early 70's, *Chadwick-Helmuth* invented a method called strobe light tracking. While a competent method, its downside is that it requires significant operator skill level. Making use of a strobe light and reflective blade tips, this method requires the operator to manually adjust a dial “and visually locate a group of targets in space and remember their relative locations.”[Johnson, History] This method was abandoned by most mainly because of the skill required to perform it properly.

Then, in the 1980's, the electro-optical method became popular again, primarily due to new developments by *Stuart Hughes*. Up-to-date electronics and technology made this the method of choice and it is still the primary method used today. [Johnson, History]

2.4.2 Rotor Balance History

The first methods used to balance helicopter rotor blades were little more than simply a static balance of blades, trying to match weights in order to create as symmetrical a rotor weight as possible. Soon enough there was a demand for improved smoothing methods, so technicians found themselves mounting vibration measurement devices on the rotor in conjunction with a strobe light to determine the amplitude of imbalance and phase angle. This procedure would show how much weight needed to be added and where it needed to be added, much like a tire-balancing machine. Soon, there was a recognized need to be able to account for not only a mass imbalance but also an aerodynamic imbalance of the rotor blades. Techniques were developed using pitch links, trim tabs, and weights to methodically adjust blade angle of attack, camber, and weight step by step to balance the rotor system. The technician would plot amplitude and phase of vibration for each iteration and then make adjustments based on a table of values created for that particular aircraft. These “manual” algorithms required a lot of skill on the part of the technician and therefore made it hard to get good results. [Robinson, 2]

In the 1980's, as computers began to become more powerful and available, computer based algorithms were developed that made use of vibration measuring devices to develop recommended adjustments to the rotor head/blades. New digital technology has overtaken older analog methods. Digital equipment is much faster, accurate, more economical, and offering many more options. Vibration measurement devices in conjunction with computer algorithms is the approach used today in helicopter smoothing [Robinson, 2].

2.5 Typical Track and Balance Procedure

Generally speaking, RT&B procedures are very standard throughout the industry. Type of equipment and helicopter adjustments are virtually the same throughout the industry.

2.5.1 RT&B Equipment

While there are quite a few different companies that produce RT&B equipment, each having a method with their name on it, the premise of each method is very much the same. Each system uses some type of vibration sensor. A piezo-electric accelerometer, similar to the one depicted in Figure 1, is commonly used to sense vibration in a chosen direction.

Figure 1. Accelerometer

Figures 2 and 3 shows an accelerometer mounted on the tail of a U.S. Army OH-58 Kiowa located at Redstone Arsenal, AL. Figure 2 depicts a typical mount location for an accelerometer measuring vibration in the vertical plane.

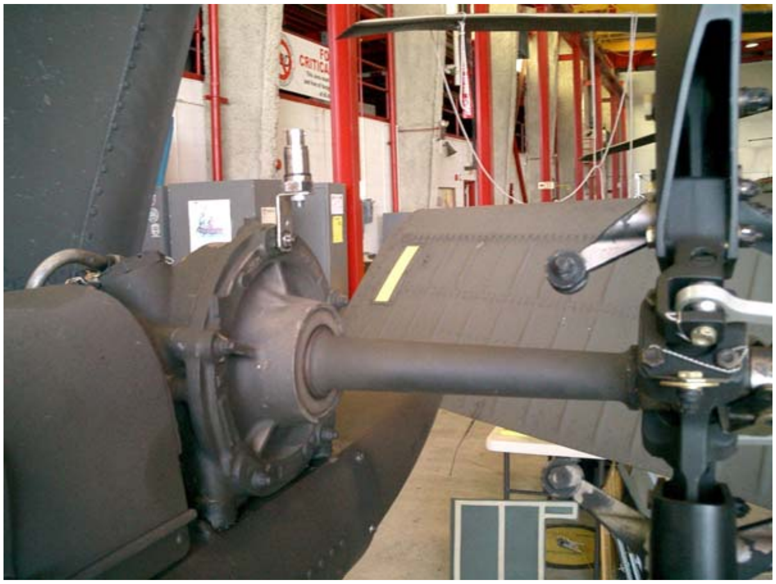


Figure 2. Accelerometer mounted on tail of OH-58 Kiowa

Figure 3. Closeup of Figure 2

In addition to the accelerometers (or other type of vibration sensor), a tachometer is also needed for input of rotor speed. The typical mount location for the tachometer is on the non-rotating ring of the swashplate. Figure 4 shows an example tachometer used for this application. The tachometer shown in Figure 4 is a magnetic pickup which produces an electrical impulse when a ferrous metal interrupter mounted to the rotating ring of the swashplate, passes close by.

Figure 4. Tachometer

The third input commonly used is from the tracker. The example tracker shown in Figure 5 is currently used by the U.S. Army for RT&B. Figure 6 shows the same tracker in Figure 5 mounted to the structure of a U.S. Army CH-47 Chinook (owned by the Akron, OH National Guard Unit). The tracker collects data on the relative location of the

Figure 5. Tracker

Figure 6. Tracker mounted to CH-47 Chinook

blade tips in the rotating disk. The above equipment is then wired to some type of data storage unit, ready to receive data. Usually, a user interface allows the user to interact with the system and visualize the vibrations. Figure 7 shows an example of a data acquisition unit and a user interface. Incidentally, the example equipment seen in Figures 1-7, is part of the U.S. Army's Aviation Vibration Analyzer (AVA) system. A typical RT&B equipment configuration on the aircraft is shown in Figure 8.

Figure 7. Data aquisition unit and user interface [AVATM, 2-1]

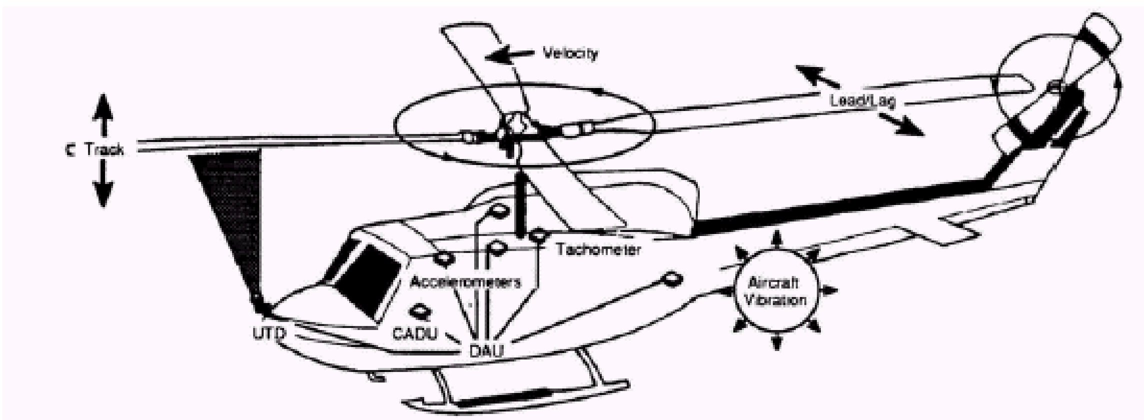


Figure 8. Typical equipment setup [AVATM, 1-2]

The problem of rotor track and balance is relatively specialized, so therefore, helicopter manufacturers rely on outside companies to develop solutions for their aircraft. Traditionally, RT&B systems have been stand alone items bought and sold exclusively for smoothing. These systems were usually separate from the aircraft, requiring equipment hookup and wiring to be run each time a RT&B was on the maintenance schedule. Recently, however, there has been an industry-wide push towards integration of RT&B vibration measurements into an aircraft Health Usage and Monitoring System or HUMS. The HUMS system not only collects data required for rotor smoothing, but monitors vibrations from different onboard equipment as well. The HUMS systems are collecting data continuously for monitoring of overall aircraft health. The idea is to detect trends in vibration data, indicating component failure or preferably a warning which gives the time left to component failure. While stand-alone RT&B systems certainly still exist, the preferred data collection is through some sort of HUMS.

2.5.2 *Aircraft Adjustments*

Typically, the data received from the above hardware is fed through an algorithm which determines the best adjustments to make to smooth the aircraft vibrations. Possible adjustments that can be made to the helicopter rotor/blade assembly include weight addition or subtraction, blade sweep adjustment, pitch link adjustment, or trim tab adjustment. While, obviously, each company designs their aircraft slightly differently, the RT&B adjustments are all very similar from aircraft to aircraft. Most helicopters have similar designs for adding weight. On a typical four-bladed helicopter, the root of two adjacent blades has weight that is added or taken away. Each blade has the capability of having weight added to it but the two adjacent blades are the only ones touched because adding weight to a blade is the same as subtracting from the opposite one. Weight adjustments correct for lateral vibrations in the aircraft. Figure 9 shows an example of the weight pins found on the U.S. Army's AH-64 Apache. Figure10 shows another blade on the same Apache with weight added to it.

The U.S. Army's UH-1 Huey is a two-bladed helicopter that is designed to hold lead pellets in the rotor head. If an imbalance is detected and weight must be added, ounce-sized lead pellets are added to either side to correct the imbalance. Some helicopters have the ability to adjust blade "sweep," moving it forward or aft. This adjustment is also made for lateral vibration smoothing.

Pitch link adjustments are another common adjustment made to smooth a rotorcraft. The swashplate moves in response to the cyclic and collective inputs of the

Figure 9. Weight pins on AH-64 Apache

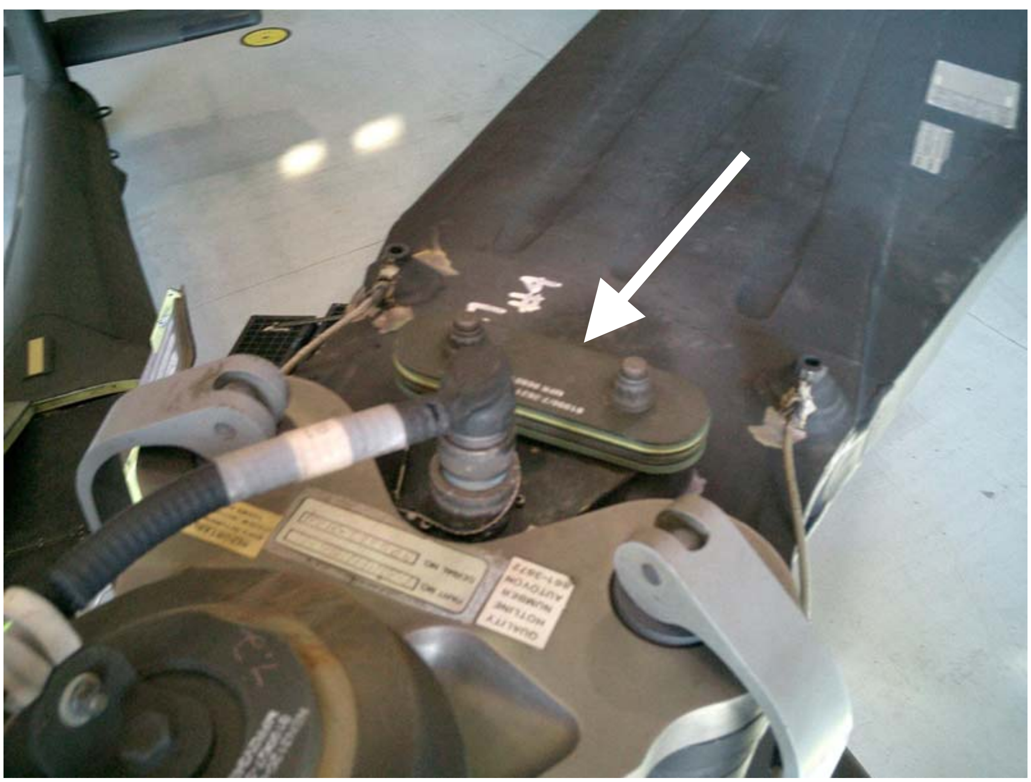


Figure 10. Weight added to blade on AH-64 Apache

pilot, and pitch links make the connection between the rotating ring of the swashplate and the pitch varying housing on the rotor blade. The pitch link on each blade can be adjusted

separately and therefore, the angle of attack of each blade can be adjusted individually. Typically, a helicopter will have a locking turnbuckle that can be extended or compressed, therefore changing blade angle of attack.

Figure 11 shows an example of an adjustable pitch link on a U.S. Army AH-64 Apache. In this case the turnbuckle is extended to increase angle of attack and

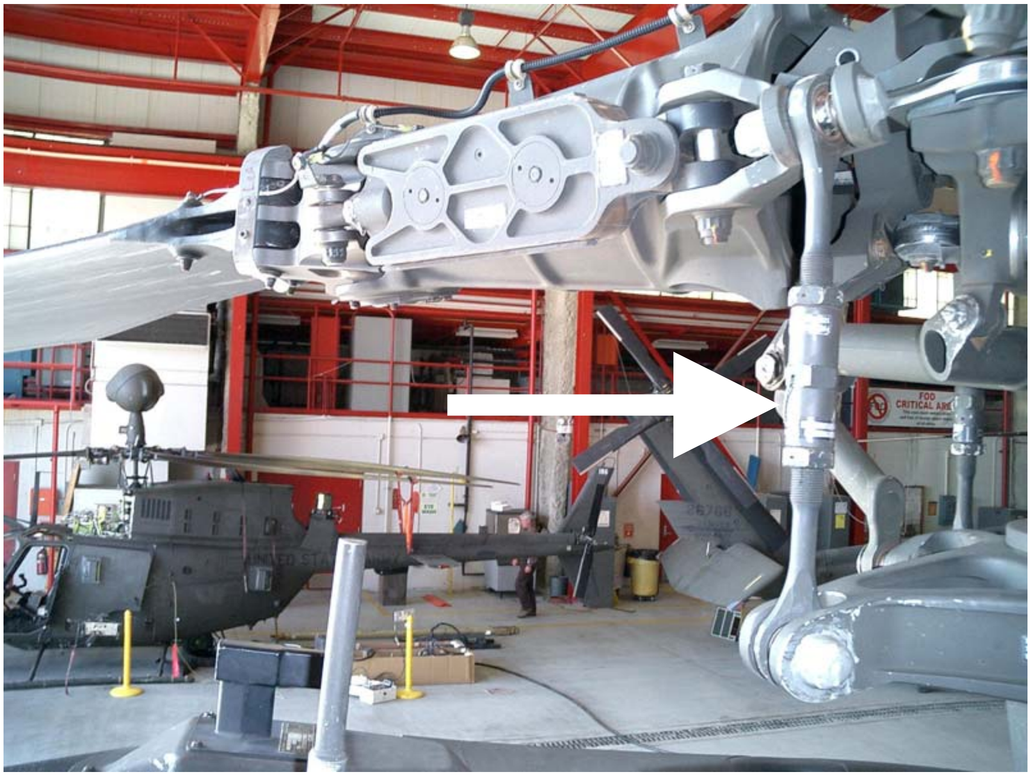


Figure 11. Pitch link on AH-64 Apache

compressed to decrease angle of attack. Angle of attack of the blade affects the drag and lift properties of the individual blade. Usually correcting for vertical vibrations will call

for a pitch link adjustment, however, as an example, increasing the angle of attack on a particular blade will produce the desired increase in lift, but it also increases drag on the blade causing the blade to want to "lag." Any change in lead/lag can affect the lateral balance. In this way, the adjustments are closely related and affect one another.

The other adjustment that can be made to correct for vertical vibration is a trim tab adjustment. Figure 12 shows a typical airfoil cross-section without a trim tab.

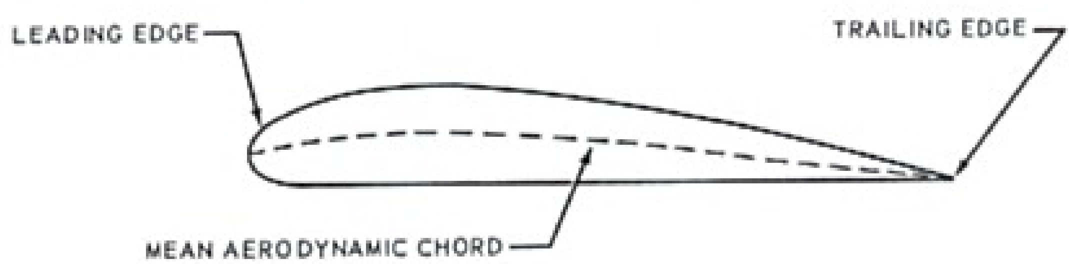


Figure 12. Typical blade cross section [Chinook]

Trim tabs are attached to the trailing edge of each blade and usually they are designed to be adjusted by manually bending them up or down by the prescribed angle amount. They are essentially the same as a "flap" on a fixed wing aircraft. The purpose of the trim tab is to effectively increase or decrease camber of the airfoil (blade) which, according to basic aerodynamic theory, increases or decreases blade lift. Figure 13 shows the same

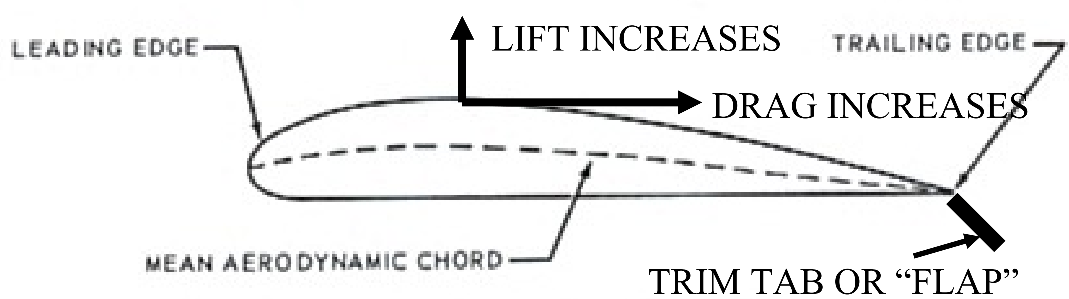


Figure 13. Airfoil with trim tab added [Chinook]

blade cross section as Figure 12 except a trim tab has been added to the trailing edge. Again, lift and drag always go hand and hand, meaning an increase in lift also gives an increase in drag. Figure 14 shows the trim tab on a blade of a U.S. Army AH-64 Apache. The Apache is unique in that the trim tab spans the entire length of the blade.

Figure 14. Trim tab on blade of AH-64 Apache

Most manufacturers have only short trim tabs on their helicopter blades. Figure 15 shows the trim tab attached to the trailing edge of a blade found on the U.S. Army's OH-58 Kiowa. Trim tabs are adjusted using a specially designed tool. Figure 16 shows an example of a trim tab bending tool made by *Chadwick-Helmuth*. The handle of the tool is pushed or pulled vertically for bending while the dial indicator measures the bend

amount. The Kaman H-2 is unique in that it was designed with a dynamic trim tab that can be adjusted by the pilot in flight until the aircraft was smooth. [Whitten, 2004]

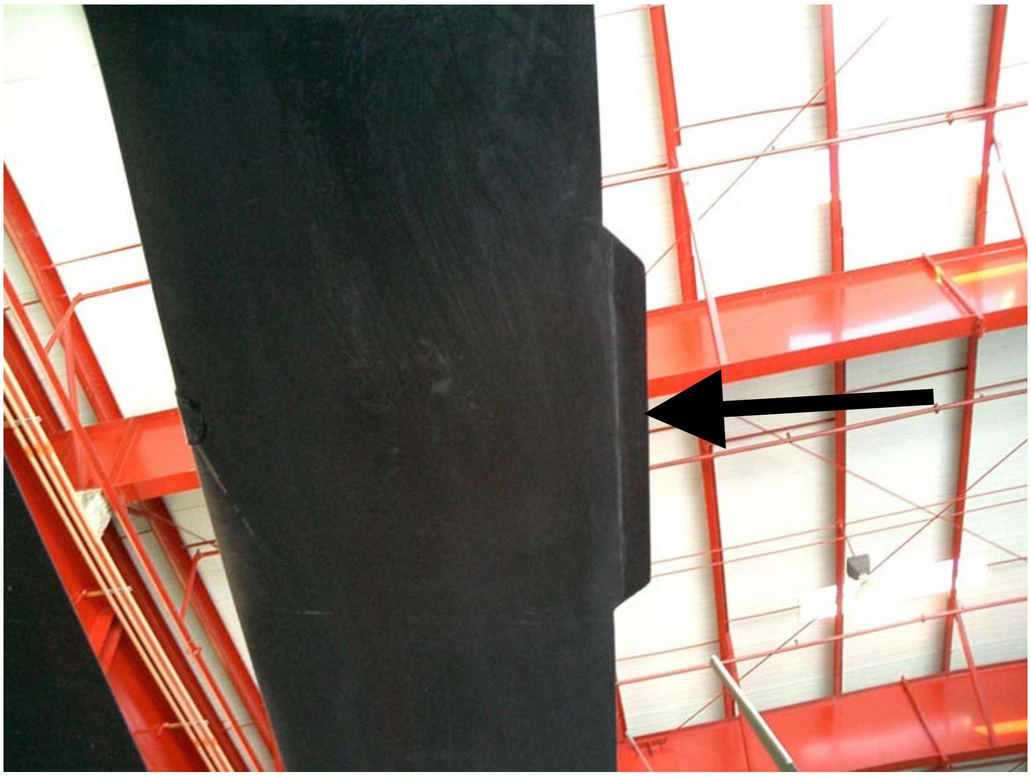


Figure 15. Trim Tab on OH-48 Kiowa Blade

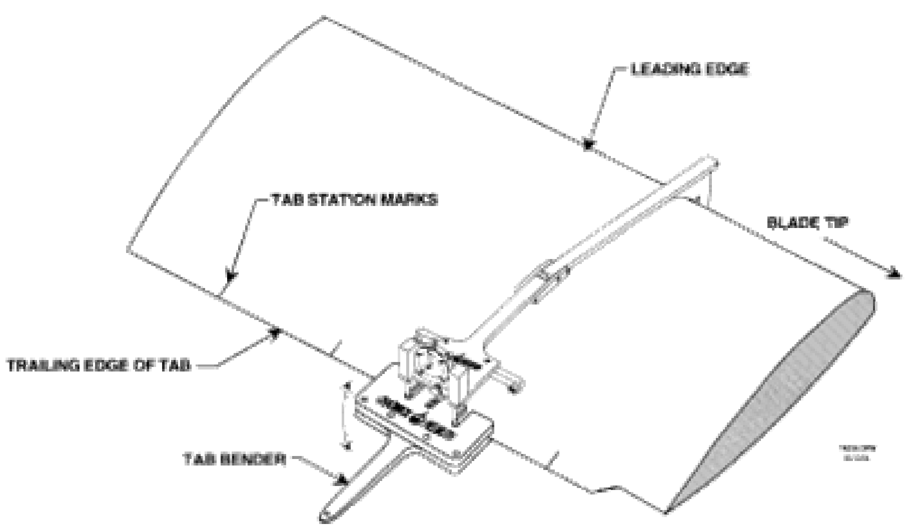


Figure 16. Tab bending tool [www.chadwick-helmuth.com]

2.5.3 *Typical Smoothing Operation*

If an aircraft rolls off the assembly line or a blade is replaced, a smoothing operation must be performed from the beginning. The first step in a smoothing operation is to statically balance the rotor blades. Static balance is accomplished by matching the chord moment and span moment of all the blades. A test jig with load cells is usually used to accomplish this. Weights are added to the blade in various locations or "pockets," set up by the manufacturer, to correct for non-uniformities.

The second step is to achieve perfect ground track. The aircraft rotor assembly is brought up to speed and the tracker is used to measure track differences in the individual blade track. Then, based on the measurements, usually pitch link adjustments are made to correct for these track differences. Perfect track is the starting point for the vibration smoothing process.

After ground track is accomplished, a ground vibration check is performed. The rotor assembly is, again, brought up to speed on the ground while vibration data is collected. This data is used to determine what adjustments need to be made to correct vibrations. The goal for the ground vibration check is to bring the aircraft within safe acceptable flying limits.

As soon as vibration levels are low enough to permit safe flying, test flights can be performed. Vibration levels in the aircraft structure are very dependent upon flight conditions. Vibrations are known to vary primarily with airspeed. Ideally, vibration data would be taken at every speed to create a complete database of the vibration state. However, this would be very impractical, as the aircraft can fly at an infinite number of speeds. The convention in industry is to use a finite number of acquisition speeds. Each

company may have a different set of flight conditions to establish their test conditions but a common example would be to collect data 1) at hover 2) 80 knots forward flight 3) 120 knots forward flight 4) 150 knots forward flight. A test flight is done and data is collected at each flight condition. After flight data is collected, the data will be used as input to an algorithm, which determines the appropriate adjustments necessary to smooth the aircraft. Each of these test flight/data acquisition/aircraft adjustments together are known as one iteration in the RT&B process. Obviously, the goal is to smooth the aircraft to acceptable levels in as few iterations a possible.

Usually, RT&B is performed during routine intervals as part of regular maintenance. Any time changes are made to the rotor/blade assembly (e.g. a blade is replaced), a rotor track and balance must be performed.

[Studer, 2004]

2.6 Why Track and Balance?

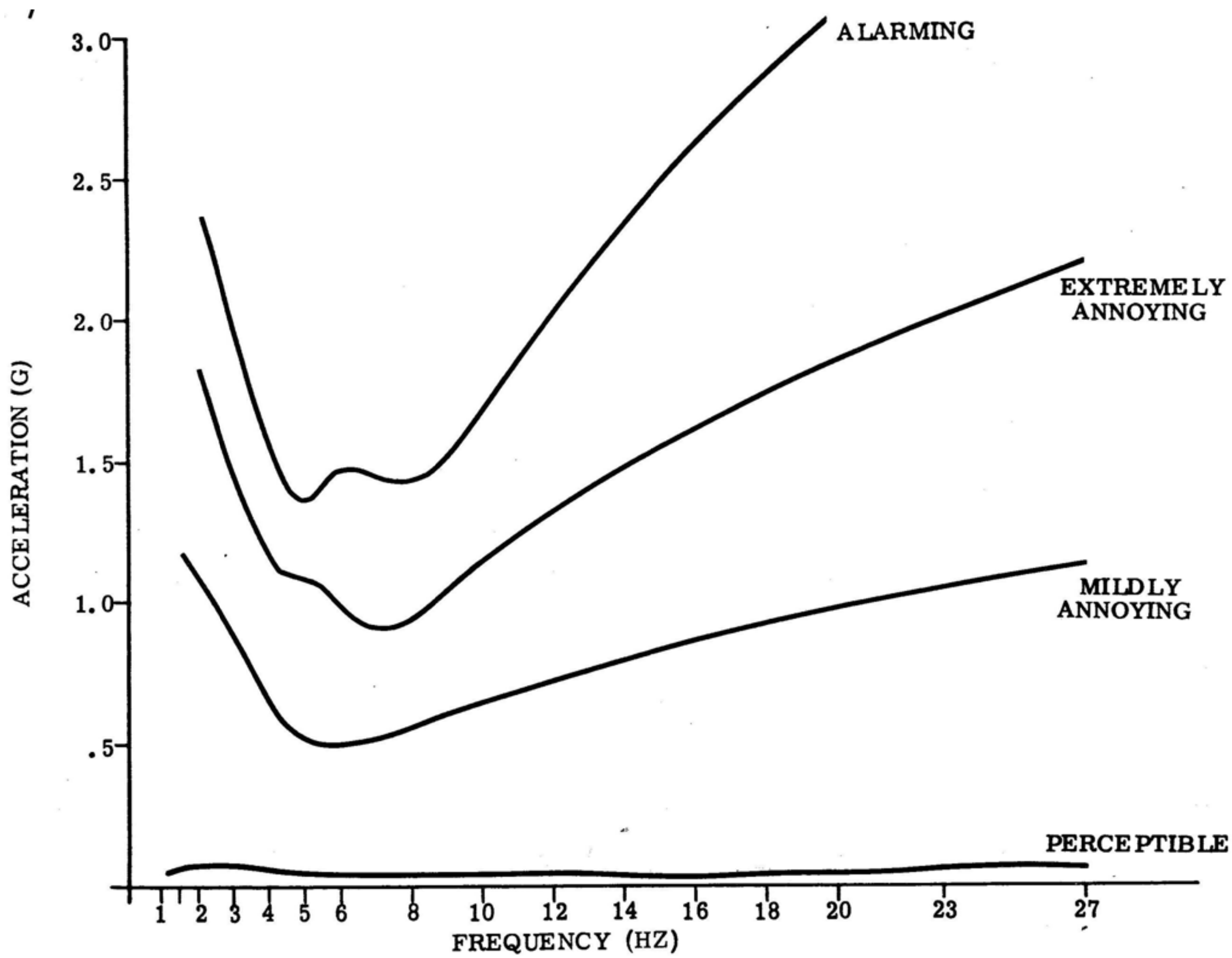
Why is rotor smoothing important? Excessive vibration levels over time can lead to crew fatigue, avionics damage, and structural fatigue of the aircraft. Obviously, any one of the above can be detrimental to the mission and therefore, should be avoided.

2.6.1 Vibration Affecting Humans

Research has shown the detrimental effects vibration can have on the human body functions. A study was published jointly by the Office of Naval Research and Boeing [Human Factors, 1969] in which the subjective human response to different vibration levels is defined. Figure 17 shows the result of the subjective test illustrating the different levels of reaction to vibration. In this same study, effects of vibration on human sensory-motor processes was noted. The study investigated the effect human vibration

has on speech and hearing intelligibility, visual performance, horizontal and vertical compensatory tracking, response to workload, and general effects on crew activities. Results showed that while not every sensory-motor process was affected (at least from the results of this particular study) there were significant negative effects from the vibration levels. The speech and hearing intelligibility test was inconclusive, as "[it was] reported that binaural threshold increased with vibration, but non-systematically. The changes which were noted were judged too small to have operational significance. Vibration likewise had little effect on speech intelligibility, except that subjects tended to speak in short bursts under the lower frequency vibration conditions." [Human Factors, 28] The results of the visual performance study concluded that "vibration severity and frequency affected readability." [Human Factors, 28] Figures 18, 19, and 20 show the results of the visual performance study. The explanation for the dramatic decrease in readability at 10Hz is explained by the coinciding critical flicker frequency of the human eye. Another study tested different lighting conditions in combination with different vibration levels. Again, the results consistently show a trend in reduced reading performance with increased vibration levels. An interesting finding resulting from this study was that red light seemed to prevent reading decrement in comparison with white light.

Human horizontal and vertical compensatory tracking was also studied. Results showed that vertical tracking was negatively affected by vibration, while horizontal was not affected severely. Figure 21 shows the results of the test. "The relationship between



SUBJECTIVE HUMAN VIBRATION RESPONSE CURVES (CHANEY, 1964)

Figure 17. [Beaupeurt, 20]

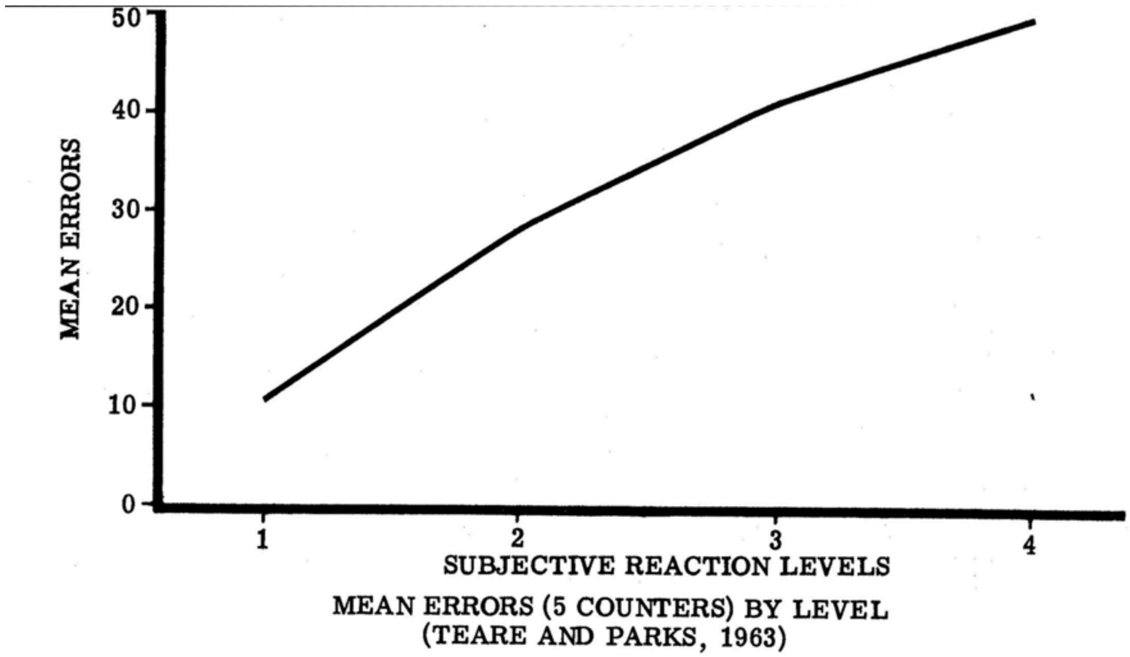


Figure 18. [Beaupeurt, 30]

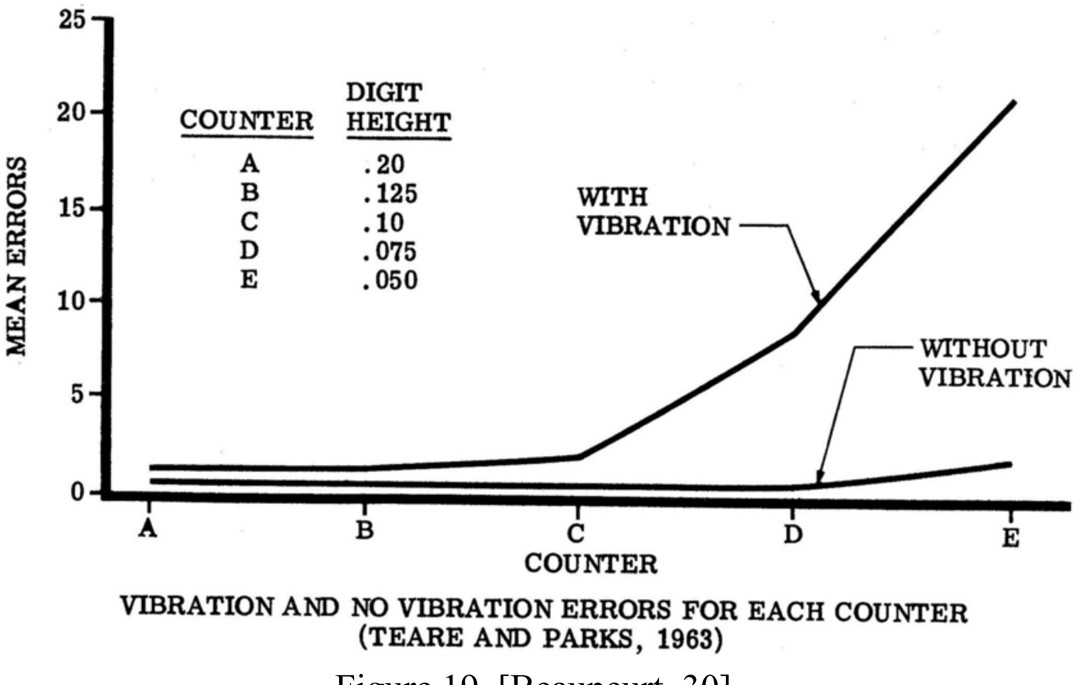
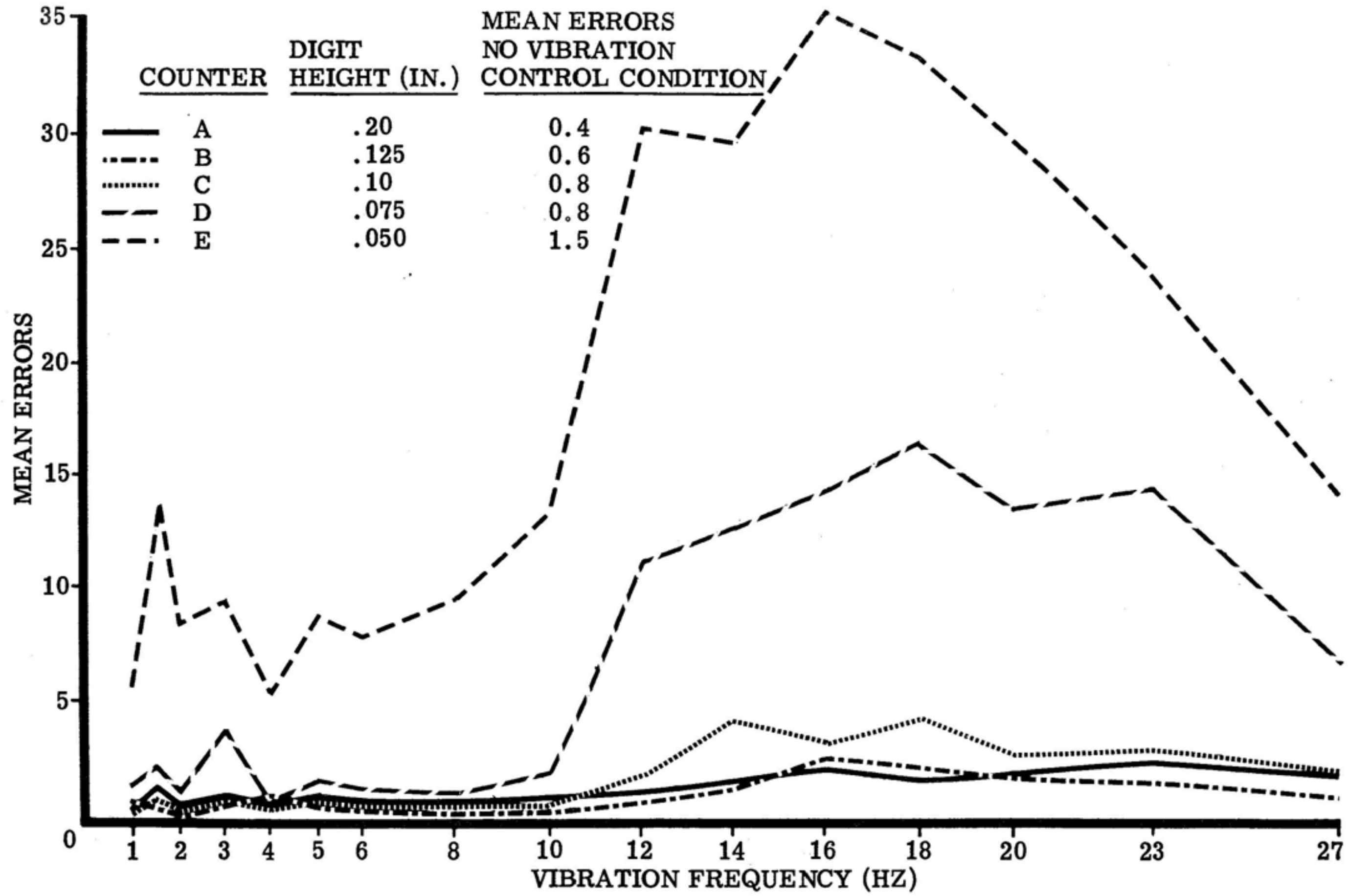


Figure 19. [Beaupeurt, 30]



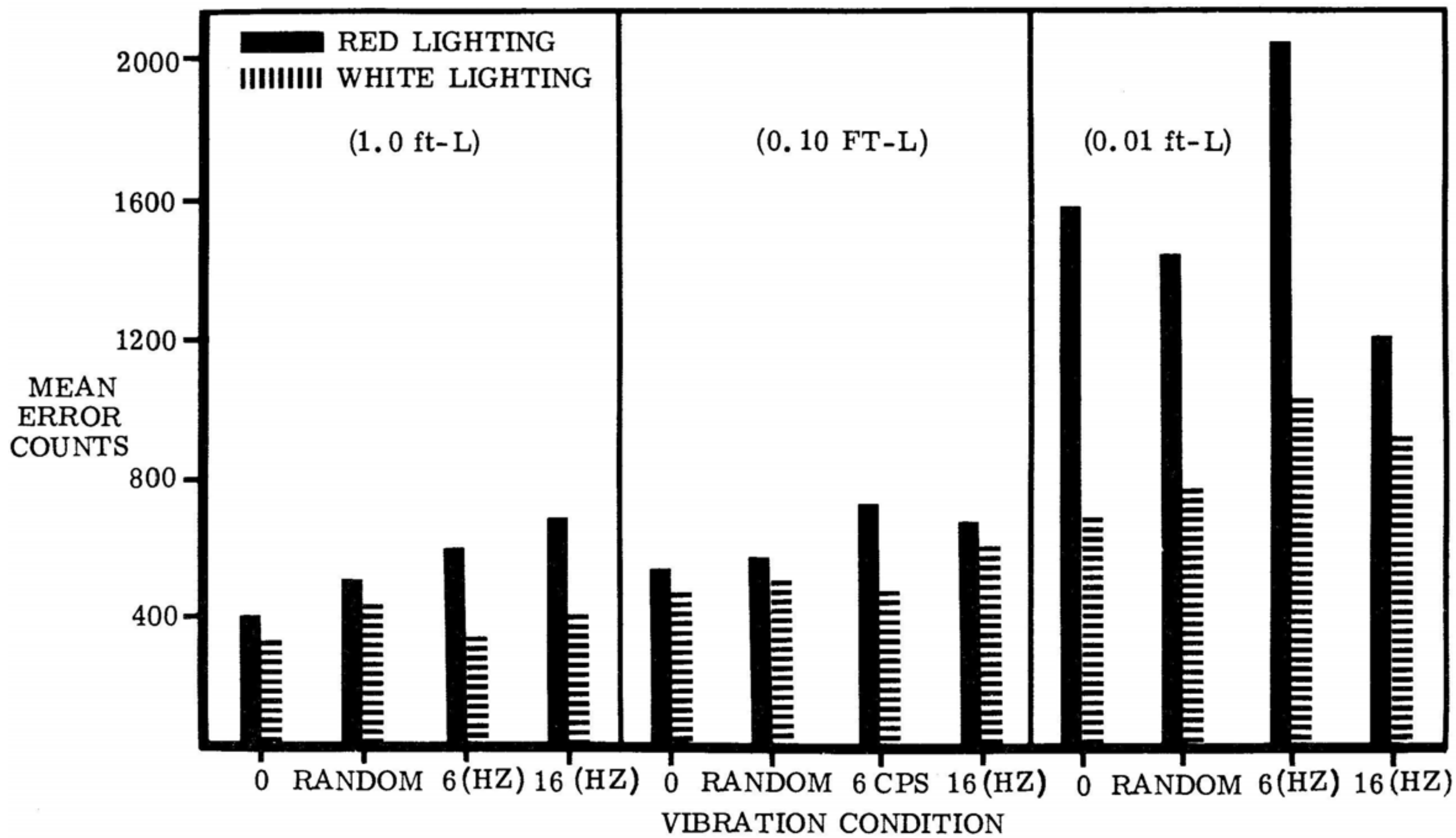
MEAN ERROR (BY FREQUENCY) FOR EACH COUNTER
(TEARE AND PARKS, 1963)

Figure 20. [Beaupeurt, 31]

vibration severity and compensatory tracking was explored by Chaney and Parks, whose seven subjects performed wheel, column, and foot tracking tasks under vertical whole body vibration . . . of special interest . . . is their finding that tracking proficiency decreases systematically as vibration severity increases." [Human Factors, 38] In fact the study "found that the immediate effects of vibration were indicated on the terrain following task in which tracking under vibration was 39 percent poorer than tracking without vibration." [Human Factors, 41]

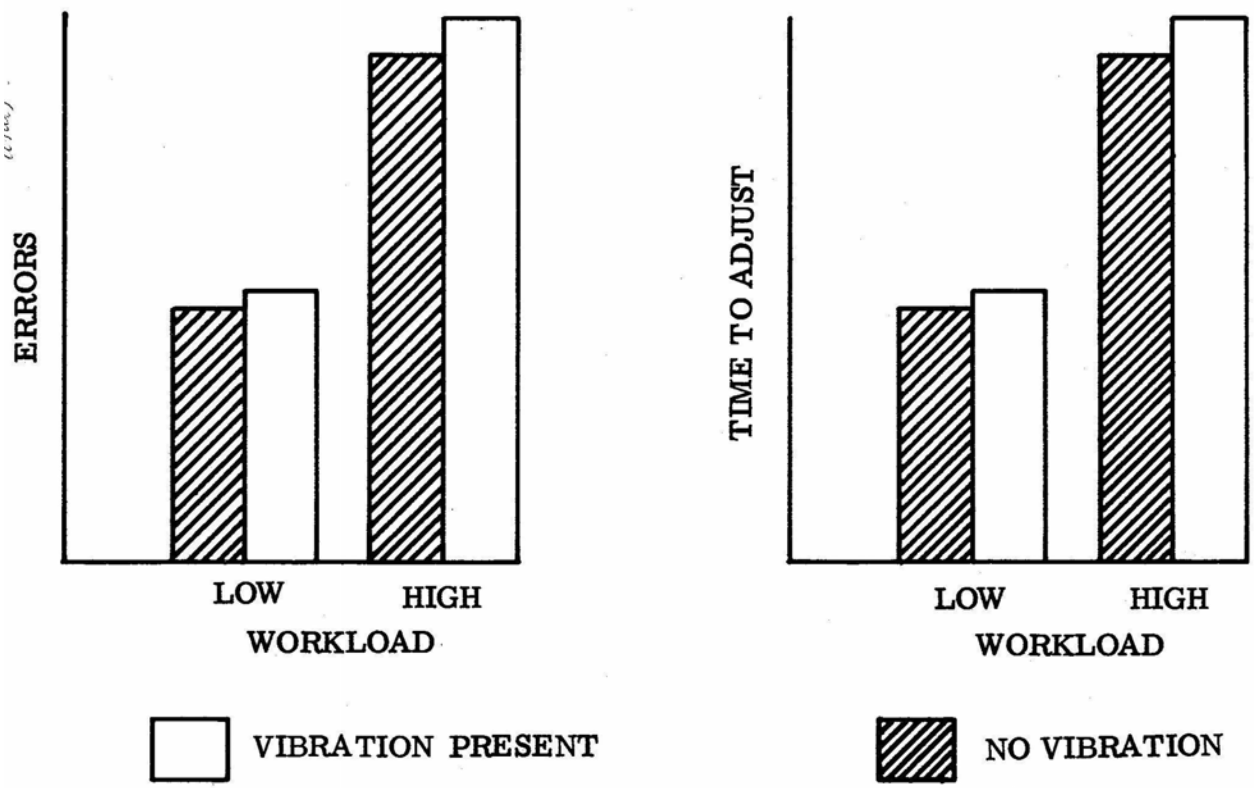
Vibration and workload was also studied, by evaluating the test subjects' ability to adjust a three-inch dial indicator using a large and small knob, vertical and horizontal levers, and vertical and horizontal thumbwheels. Time to complete the task was the primary evaluation means. Figure 22 shows the results of this testing. Increased vibration seemed to consistently increase errors and time required to make proper adjustments.

In summary, the Boeing/ONR report showed that there is a direct relationship between vibration level and degradation of human sensory-motor processes.



MEAN HEADING TRACKING ERROR SCORES (MORRIS, I966)

Figure 21. [Beaupeurt, 37]



WORKLOAD VERSUS VIBRATION (CHANEY & PARKS, I964b)

Figure 22. [Beaupeurt, 40]

2.6.2 Vibration Affecting Component Life

Excessive vibration also shortens the life of components and subsystems found on an aircraft. A study performed in Fort Eustis, Virginia by the Sikorsky Aircraft Division explored the effects of vibration on helicopter reliability and maintainability. [Veca, 1973] The study compared two equivalent groups of USAF H-3 helicopters, one group was equipped with a rotor mounted bifilar vibration absorber and the other without this absorber. The vibration absorber found on the H-3 helicopter absorbs the n-per-rev higher harmonics of vibration from the main rotor. RT&B works to correct the 1-per-rev vibration directly while indirectly correcting the n-per-rev. The absorber does not replace the need for RT&B.

The Fort Eustis testing showed a significant increase in failure rate of the helicopter group without the vibration absorber. The vibration absorber decreased vibration by 54.3% and as a result the overall aircraft failure rate dropped by 54% and corrective maintenance was reduced by 38.5%. In addition, life cycle costs were shown to be reduced 10% by the reduced vibration levels. In the end, the study showed that improved reliability and reduced maintenance/life-cycle costs can be achieved by reducing vibration levels. The findings also suggest that the aircraft's useful life can be extended purely by a reduction in vibration levels.

Table 1 shows a comparison of data pulled from USAF records on normal maintenance and subsystem reliability of the two groups of H-3s. Failure rates were calculated by taking the ratio of total number of recorded failures and total accumulated flight hours, averaged for the two groups. The second comparison in Table 1 was calculated by taking the ratio of total required maintenance man-hours to total flight

hours of the aircraft. Table 1 illustrates the dramatic impact of excessive vibration on health of the aircraft.

Table 1. [Veca, 27]

TOTAL AIRCRAFT SYSTEM COMPARISON
RELIABILITY AND CORRECTIVE MAINTENANCE

Aircraft Subsystem	Failure Rates (10^{-3}) W/Out Absorber	With Absorber	Failure Rate	-MMH/KFH W/Out Absorber	With Absorber	MMH/KFH
Airframe	223.7	107.8	115.9	592.3	209.7	382.6
Drive	108.7	47.6	61.1	371.8	216.5	155.3
Utilities	64.1	13.8	50.3	106.4	26.3	80.1
Landing Gear	91.5	44.8	46.7	289.6	189.8	99.8
Lights	119.6	29.3	90.3	240.7	45.6	195.1
Fuel	56.2	22.8	33.4	118.8	50.8	68.0
Flt. Control	58.4	22.8	35.6	209.5	60.5	149.0
Rotor	80.4	51.0	29.4	321.4	278.8	42.6
Cockpit/Fus.	33.1	9.9	23.2	48.9	23.2	25.7
Electrical	35.6	12.4	23.2	79.4	26.2	53.2
Hyd. Power	37.1	17.1	20.0	76.3	19.9	56.4
Inter Comm.	39.5	21.2	18.3	71.2	49.7	21.5
Radio Nav.	65.5	50.2	15.3	209.0	217.7	-8.7
Air Cond/Heat	27.1	18.3	8.8	95.7	36.1	59.6
Auto Pilot	28.4	16.6	11.8	94.2	88.6	5.6
Emer. Equip	12.7	2.4	10.3	15.9	1.4	14.5
Aux Power Unit	44.5	36.2	8.3	125.9	107.4	18.5
HF Comm.	14.9	6.7	8.2	69.3	33.5	35.8
UHF Comm.	23.1	17.6	5.5	67.9	93.1	-25.2
IFF	8.2	2.9	5.3	21.9	12.3	9.6
Misc. Comm.	8.7	4.7	4.0	13.4	9.3	4.1
Weap. Del.	1.9	0.2	1.7	4.3	0.3	4.0
Emer. Comm.	0.2	0.2	0	0.2	0.3	-0.1
VHF	9.2	9.4	-0.2	38.8	36.4	2.4
Radar Nav.	40.0	40.4	-0.4	163.7	188.2	-24.5

* Minus sign indicates an increase in rate.

Aircraft component reliability is also affected by vibration. The Fort Eustis study compared component reliability on board both groups of H-3s. The results of the comparison show a dramatic difference in reliability for nearly every component. Appendix A includes tables comparing reliability which clearly show the negative effect vibration can have on component reliability.

Vibration reduction also decreases life-cycle cost of the aircraft. Table 2 illustrates the life-cycle savings per aircraft resulting from vibration reduction. The study found that savings over the life-cycle of the aircraft from vibration reduction totaled over $350,000, which is approximately a 10% savings.

The results of this study suggest that component failure can be blamed on fatigue over time, and that reducing vibration levels can therefore increase the usable life of the aircraft components. An increased component life and reliability also saves maintenance man-hours and, therefore, money as proven by the cited study.

2.7 Chapter Summary

Track and balance are two terms describing the dynamics of the rotating rotor blade assembly. Track refers to the relative path of the blade tips to one another, while balance includes a mass balance as well as an aerodynamic balance. The primary method of track used today is electro-optical tracking and the method of balancing has evolved into computer aided algorithms. Necessary equipment for a RT&B process includes accelerometers, a tachometer, a tracker, some type of data acquisition unit, and a user interface. The equipment is used to gather vibration data on the aircraft, which leads to rotor adjustments to smooth the aircraft. Typical adjustments include: weight changes, pitch link lengthening or compressing, and trim tab adjustments. RT&B is performed on

an aircraft to decrease vibration levels. Decreased vibration levels are desired because excessive vibration has a negative effect on both human performance and component life.

Table 2. [Veca, 94]

LIFE-CYCLE SAVINGS PER AIRCRAFT RESULTING FROM VIBRATION REDUCTION					
	In-The-Pocket Savings		Savings Due To Increased Utility		
SYSTEM	Maintenance	Spares	Mission Reliability	Availability	TOTAL
Airframe	46,356	8,654	424	17,351	72.785
Drive	18,816	69,762	5,807	7,043	101,428
Utility	9,705	7,292	798	3,633	21,428
Landing Gear	12,092	6,431	824	4,526	23,873
Lights	23,638	951	150	8,848	33,587
Fuel	8,239	7,007	237	3,084	18,567
Flight Controls	18,053	18,077	847	6,757	43,734
Cockpit	3,114	1,178	0	1,166	5,458
Hydr. Power	6,833	2,642	0	2,558	12,033
Interphone	2,605	1,334	0	975	4,914
Radio Nav.	-1,054	2,015	0	-395	566
Airconditioning & Anti-Ice	7,221	1,052	0	2,703	10,976
Electrical	6,446	8,182	923	2,413	17,964
TOTAL	162,064	134,577	10,010	60,662	367,313

III. Algorithm Types

3.1 Introduction

The best method of visualizing helicopter vibrations for analysis is through use of a polar chart. Amplitude and phase angle of vibration are plotted on the polar chart. Figure 23 shows an example of a polar plot used to plot vibration level. Industry standard for vibration amplitude is to report it in ips (inches per second). The accelerometers measure in units of g's. This data undergoes a fast Fourier transform (FFT) from the time domain into the frequency domain, and is then integrated to give magnitudes in mean vibration velocity rather than g's. Figure 23 shows an example of a frequency spectrum which is vibration amplitude (ips) plotted vs. frequency (usually cpm). The dominant 1-per-rev frequency can be seen followed by the higher harmonics of decreasing amplitude.

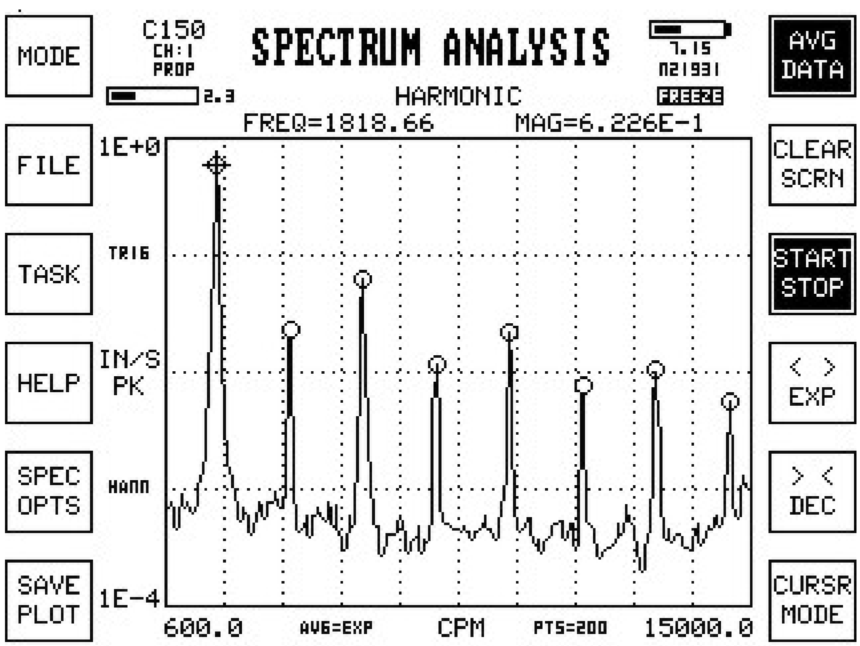


Figure 23. Frequency spectrum [www.dssmicro.com]

3.2 Algorithm Overview

All current RT&B systems work very similarly. Each method relies on predictable aircraft response to adjustments. A database of response to different adjustments is created empirically for each aircraft or "type" of aircraft. Test flights are performed where single adjustments are made beforehand and the response of the aircraft from the vibration data is recorded. After a database is "complete," the information can be used by an algorithm in future smoothing problems to determine the proper adjustments to make to achieve a smooth aircraft. The "trick," or proprietary part of the algorithm is developing the proper adjustment solution from an arbitrary vibration magnitude and phase angle. In each adjustment case, only discrete adjustments can be made, therefore, the algorithm must account for this and develop a compromise in the case where an initial solution calls for a fractional adjustment to be made. [Studer, 2004] Current algorithms can be categorized into two categories: non-learning and learning.

3.2.1 Non-Learning Algorithm

The non-learning type algorithms rely on aircraft response to adjustment to be consistent with that type of aircraft, relying on the initial database developed, as discussed above. Figure 24 shows an example of a polar plot used to visualize aircraft vibration. In this example, a preliminary test flight is done without any adjustment to the aircraft. This initial test establishes a baseline, and in this example, the baseline is a vibration of 0.5 ips at a phase angle of 45º. After establishing a baseline, an arbitrary weight adjustment is made on this aircraft, adding 5 oz. of weight to the black blade. Then, a second test flight is performed, with data recorded just as before in the first test flight. The results of the second test flight show a new vibration amplitude of 0.5 ips at

225º phase angle. These two test flights show that for this particular aircraft, adding weight to the black blade results in 0.2 ips of magnitude change per one oz. of weight added, in the direction of 225º on the polar chart. The 0.2 ips/oz. is merely one of the many "coefficients" developed and entered into the database for that particular aircraft. The algorithm then calls on this information from the database when developing an adjustment solution for the particular vibration magnitude and phase angle on the aircraft. [Keller, 2004]

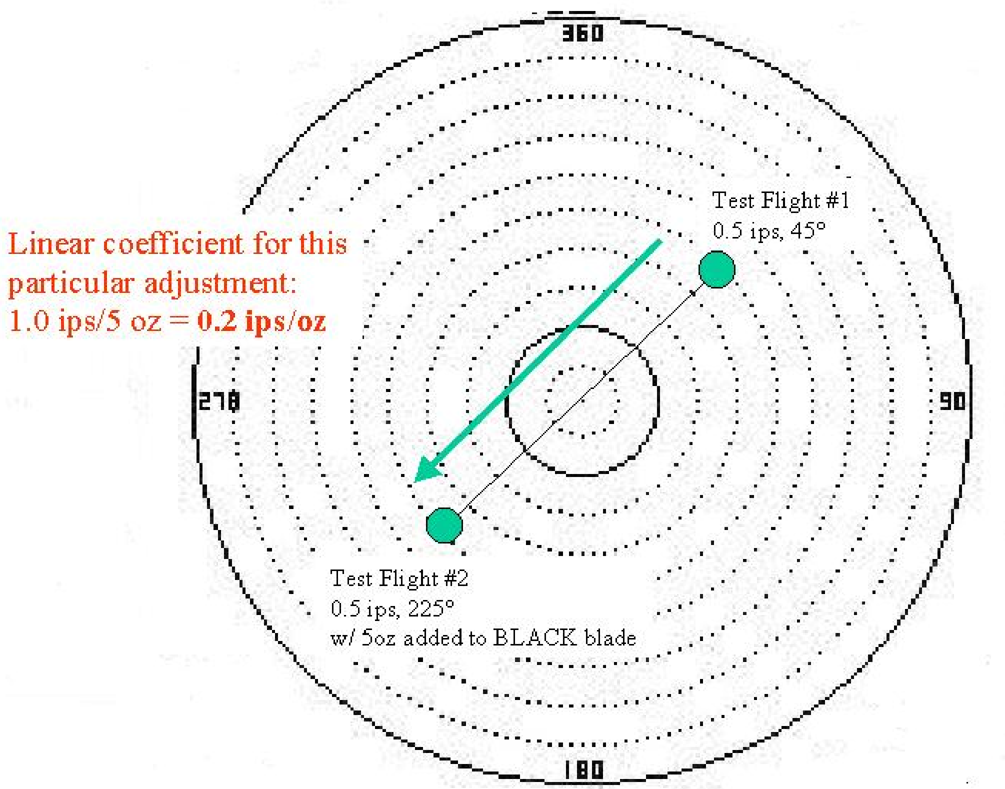


Figure 24. Coefficient development using a polar plot

The companies using a non-learning type algorithm are *Chadwick-Helmuth, Dynamic Instruments, Goodrich, Helitune, Intelligent Automation Corporation, RSL Electronics, and Smith Aerospace.*

Chadwick-Helmuth is a company based out of El Monte, CA. Recently, the company was purchased by *Honeywell*, and now calls itself *Honeywell Chadwick*. *Chadwick-Helmuth* was one of the original RT&B companies, started in 1954 by Jim Chadwick. The company carries a broad range of products designed to smooth vibrations in both fixed and rotary wing aircraft. The product range starts with the entry level "Vibrex 2000" and ends with a "Vibralog" HUMS. [Welborne, 2004]

Dynamic Instruments is a company based in San Diego, CA. *Dynamic Instruments* is the creator of the ATABS/VATS (Automated Track and Balance Sets/Vibration Analysis Test Sets) RT&B system used by the U.S. Navy/Marine Corps. It has been around since the early 1980s and is just recently starting to be replaced by a new *Goodrich* HUMS. [Whitten, 2004]

Goodrich (formerly known as *BFGoodrich*) is a large company based out of Charlotte, NC. Recently, (past ten years) they won the contract with the U.S. Navy and U.S. Marine Corps for its new IMD HUMS (Integrated Mechanical Diagnostics Health and Usage Monitoring System). Still in the testing phase at Patuxent River NAS, this system is a big upgrade from the portable ATABS/VATS system currently being used by the Navy/Marine Corps. [Hollins, 2004]

Helitune is a small company located in Devon, England. *Helitune* supplies RT&B systems primarily to the U.S. Coast Guard. They offer several different systems for rotor smoothing in their product line known as "Rotortuner." [www.helitune.com]

Intelligent Automation Corporation (IAC) is the developer of the new system undergoing testing by the U.S. Army. Their system is a HUMS known as VMEP (Vibration Management Enhancement Program) or AVA II (Aviation Vibration

Analyzer). The VMEP is a culmination of lessons learned over the last fifteen years or so, integrated into a permanent, on-board management system. [Keller, 2004]

RSL Electronics is a company based out of Israel. RSL recently released a new T-HUMS (Total Health Usage and Monitoring System). [www.rsl.co.il/]

Smith Aerospace is a large company with offices located both in the U.S. and England. Originally, *Stuart Hughes* (of the UK) and *Scientific Atlanta* teamed up together to create a RT&B system (which is known today as AVA). Then the two merged to create a company called *Global Associates*. *Global Associates* was then renamed later to *Smith Aerospace*, which is the company's name today. AVA is the primary system used today by the U.S. Army. [Studer, 2004]

3.2.2 Learning Algorithms

There are two companies which currently use learning algorithms to develop recommended rotor adjustments. Learning type systems use neural networks. The results of each adjustment are used to continually update the coefficients. The idea is to develop a database that is specific to the one particular aircraft, with hopes that future adjustment recommendations will be more effective than the last.

Dynamic Solutions Systems (DSS) is a small company located in San Marcos, CA. *DSS* produces a system they call "MicroVibe". The MicroVibe is a learning-type algorithm similar to what is used by *ACES*. MicroVibe only recommends a single adjustment per iteration. The downside to this is that this system typically requires more iterations than systems that call for multiple moves to be made. [Johnson, 2004]

ACES is a company located in Knoxville, TN specializing in aviation maintenance solutions. Primarily they deal with balancing different rotating assemblies

on aircraft. They carry four different products which perform helicopter rotor track and balance. The *ACES* systems use an algorithm based on only one adjustment per iteration. Each iteration tweaks the algorithm slightly, in an attempt to get more accurate results in future tests. The *ACES* system is very similar to the system used by *Dynamic Solutions Systems*. [Lucas, 2004]

3.3 *Chapter Summary*

There are two primary types of algorithms in use today for RT&B, learning and non-learning. Non-learning relies on a database developed empirically for each aircraft type used to predict an aircraft's response to adjustments. A learning type algorithm is similar, however, the database is continually updated with every iteration made to develop a more accurate aircraft database. Both types are seen among the available systems found today in the RT&B industry.

IV. Discussion, Conclusions and Recommendations

4.1 Introduction

Helicopter rotor track and balance is a very costly part of a helicopter's maintenance. Costs include: wear and tear on the aircraft, fuel, crew maintenance time, and unavailability of aircraft for mission. For this reason, every helicopter owner wishes to perform the very important smoothing of the aircraft as efficiently as possible. There are certain "problem" areas which currently plague the smoothing process.

4.2 Blade Uniformity

Blade uniformity is one of these problem areas. The reason for needing a rotor smoothing process is the result of non-uniformities. Each rotor blade, in fact, is not made equally. Today's rotor blades are relatively complex in construction. Figure 25 shows

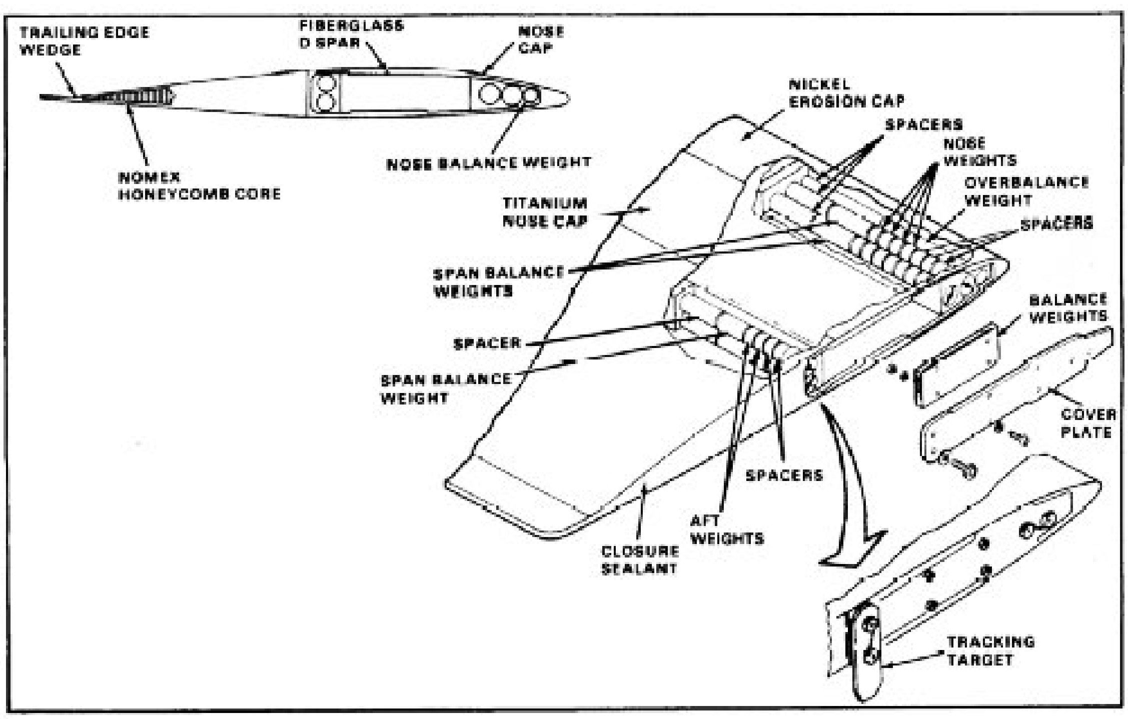


Figure 25. CH-47 Blade Construction (Chinook)

how the blades on the CH-47 Chinook are constructed. Manufacturing techniques are not perfect. In fact, the consensus in the helicopter industry is that the blades are far from perfect and practitioners assume or simply count on the fact that no two blades are identical. So even beginning with brand new blades, there will almost always be an imbalance in the rotating assembly. But manufacturing irregularities aside, there are other reasons for non-uniform blades. The military performs many of its missions with the aid of helicopters. Some of these missions include combat scenarios in which there is a chance of blade damage from enemy fire. It is common for a military helicopter blade which has been damaged in combat or otherwise to be patched and put back in service. Figure 26 shows an example of a damaged blade which has been patched.

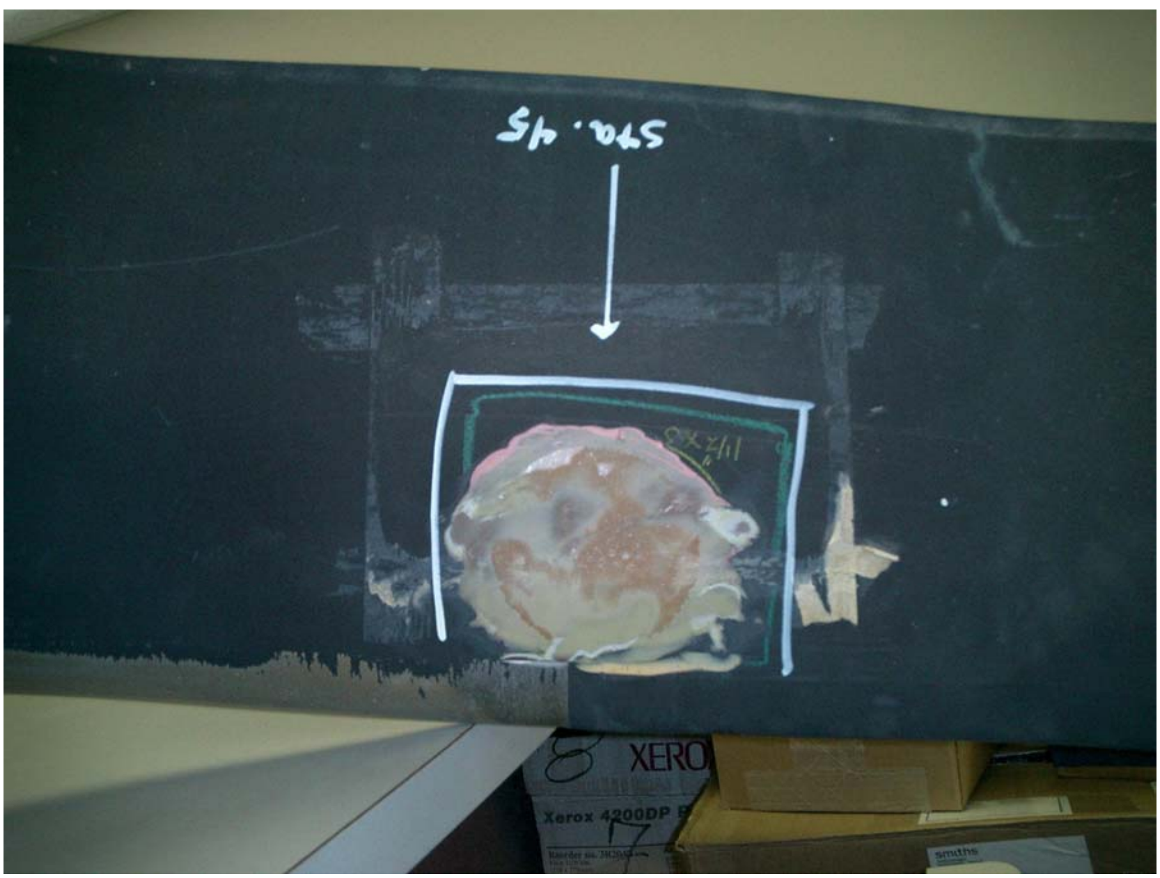


Figure 26. Patched Blade

Obviously, with a hole blown through a blade and then patch material used for a repair, the static and dynamic properties of the blade will change.

Another reason for non-uniformity in the rotor blades is the construction materials used. The honeycomb core of the blade is porous and capable of absorbing moisture. In wet, tropical climates the blades will absorb water, which, depending on the severity of the conditions, can become a big problem in terms of uniformity.

Another problem facing helicopters, currently serving, especially in the Middle East, is blade erosion. Blade erosion is a function of quantity and type of debris in the air. When the debris is sand, as in the Middle East case, blade erosion is accelerated dramatically. The erosion along the leading edge is not necessarily perfectly uniform, so it can create a permanent imbalance in the rotor assembly that must be corrected.

Simply from a blade uniformity standpoint, an initial rotor smoothing process is always necessary to correct for non-uniformities from the manufacturing. It is true that quality control can be increased and the manufacturing process could be tweaked so that all blades leave the factory nearly perfect, if not perfect, but when the cost is considered for the number of helicopters in service, this would be impractical. Plus, eventually, the work environment will change the blade uniformity. So, the bottom line is that blade non-uniformities cannot be eliminated unless drastic changes are made in design and manufacture. Therefore, these non-uniformities must be accepted and dealt with.

[Keller, Bale, 2004]

4.3 Rotor Adjustments

As stated previously, the RT&B process is very time consuming. U.S. Navy's Petty Officer Scott Beckman stationed at Patuxent River NAS explained how the maintenance crews really push to get a helicopter smooth within their eight hour shift, with a typical smoothing operation taking between five and six hours. AFIT's very own Capt. Justin Eggstaff, USMC, who is a AH-1 Cobra pilot, talked similarly about the time required to smooth a typical helicopter. He also spoke of a time when he remembers it taking over 15 hours to smooth an aircraft! [Eggstaff, 2004]

So what about the operation is so time consuming? Well, the test flight itself takes time. However, it is necessary to gather vibration sensor data while the aircraft is in flight. The test flight will always be necessary. Part of the big push towards the integrated HUMS is that test data can be collected while the aircraft is *already* in the air for a mission related flight. The argument can be made, however, that if vibration levels are too high, the aircraft will be grounded for mission related flights. In this case, specific RT&B flights are necessary. Other than the test flights themselves, which usually last no longer than ½ hour, the mechanics must make the required rotor adjustments called for by the program. Making these rotor adjustments is by far the most time consuming part of the RT&B process. On a trip to the Akron, OH, U.S. Army National Guard Unit, smoothing was being performed on a CH-47 Chinook. After a test flight, a pitch-link adjustment had to be made on a blade on the rear rotor. This one pitch link adjustment took roughly 1 ½ hours! Figure 27 shows this pitch link adjustment being performed. Figures 28 and 29 show the wire lock being installed on this pitch link. Weight addition

Figure 27. Pitch link adjustment on CH-47 Chinook

or subtraction usually isn't too difficult or time consuming. Most mechanics prefer to avoid trim tab adjustments because they can be tricky. Common adjustments are in 0.001 in. of tab movement, which often can be difficult to achieve accurately. Some tabs are physically difficult to bend as well, leading to problems with the adjustment. The fatigue life of the tab is a factor as well. Some manufacturers put a limit on the number of tab adjustments due to fatigue concerns. [Studer, 2004]

Rotor track and balance adjustments are not easy to make. No matter what algorithm is used to find the adjustment solution, the fact remains that these time

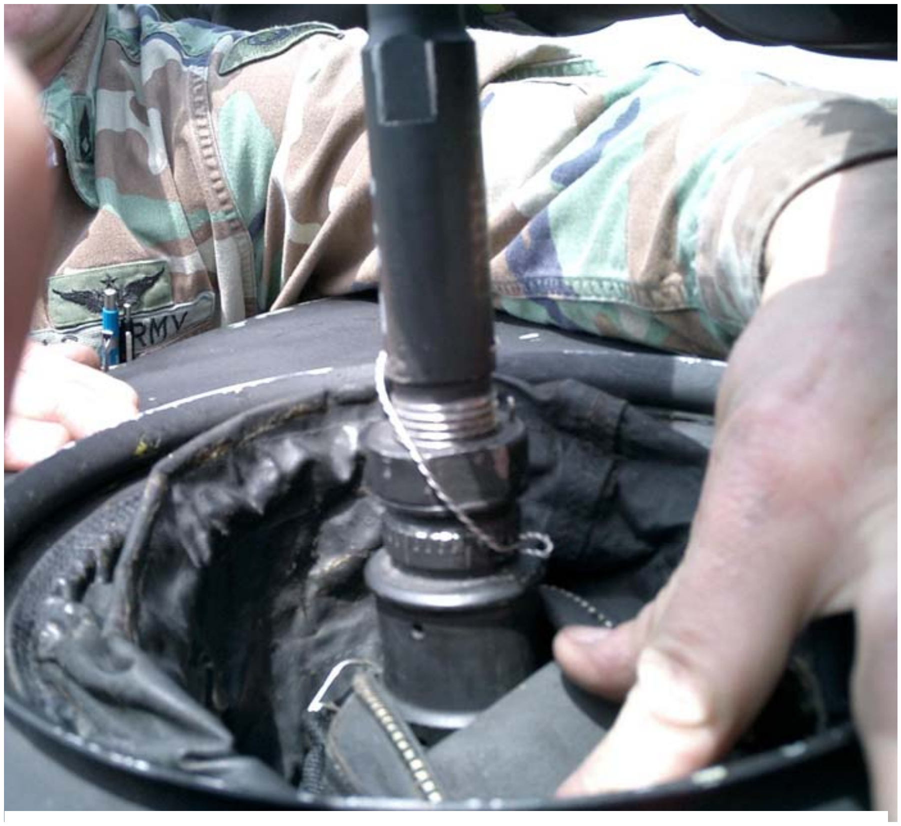


Figure 29. Pitch link lock on CH-47 Chinook

Figure 28. Pitch link lock on CH-47 Chinook

consuming adjustments must still be made. If manufacturers designed easier adjustment methods for their aircraft, required smoothing time would decrease dramatically. The best design would be one which allowed adjustments to be performed midflight. Weights that could remotely move radially as well as circumferentially around the rotor head, pitch links that could be remotely lengthened or shortened, and trim tabs which could be remotely adjusted, similar to the pilot adjustable trim tab found on the H-2, would be an ideal design. These adjustments could be made by the pilot from the cockpit, midflight, to essentially "tune" the rotor assembly until it was perfectly smooth (much like the old method of balancing a tire). As discussed previously, environmental conditions have a big impact on blade-uniformity, so this type of design would be very advantageous in climates that require frequent smoothing (e.g. sandy environments that cause heavy blade erosion).

Disadvantages to this type of design would include the likely weight addition to the existing designs, adding to the life-cycle costs of the aircraft, and the initial cost of the aircraft would likely increase. Advantages would be the huge savings in maintenance and required flight time of the aircraft, which can really add up, considering the frequency of smoothing operations and the time and cost of each iteration. Often initial cost and weight are the primary considerations to purchasing an aircraft with maintenance requirements being secondary, explaining why this design is not widespread. For example, in the military, RT&B is not considered a big priority to the contract bidders. Main emphasis is on mission effectiveness vs. initial cost/weight. However, considering the life cycle maintenance costs, RT&B *should* be a priority, and ease of adjustment should be demanded of the manufacturers and should be pushed for in

future designs. In the meantime, adjustment designs on existing aircraft must be accepted, as they cannot be redesigned and retrofitted (easily).

4.4 Equipment Reliability

Equipment reliability is another key factor in the timeliness of smoothing operations. If the equipment is unreliable, with one essential component broken, then obviously, the smoothing operation will fail. Often equipment failures can be subtle, making troubleshooting difficult. A fatigued wire which has broken inside its insulation can be tough to spot. If an accelerometer fails, reporting erroneous data, the smoothing operation will fail. Equipment with built-in diagnosis can dramatically decrease troubleshooting time. [Keller, 2004]

4.5 Mechanic Education

As a follow-on to the above discussion, in order to be an effective troubleshooter, a good complete understanding of the system is necessary. One area of the RT&B process that needs serious improvement is maintenance technician education. In general, the more educated a person is about the task, the more effective he or she is at performing the task. This couldn't be more relevant than in the process of RT&B. The more familiar the user is with the system, usually the more effective he or she is with succeeding in smoothing the aircraft. Because of the large number of variables, troubleshooting is often an important job of the technician. As stated earlier, sometimes it is impossible to smooth an aircraft with the current blade configuration. For example, if there is a problem blade that makes smoothing impossible, the maintenance technician must recognize that because any effort put into smoothing will be futile. Perhaps one of the

blades is irregular, or perhaps there is a bad component on the aircraft preventing the smoothing operation from succeeding (for example, a bad damper). If the maintenance technician does not realize this, he or she could attempt to find balancing solutions forever without results. [Bale, 2004]

Eric Bale of *Avion, Inc.* is contracted by the U.S. Army to educate maintenance crews about proper RT&B procedures. He calls himself the "myth buster." With every class he teaches, he corrects false notions of the mechanics, which often interfere with successful smoothing. One of the most common errors of a mechanic is to not trust the equipment. Many mechanics will modify adjustment recommendations to whatever he or she thinks is the proper adjustment, thinking he or she knows better than the equipment. The RT&B equipment is designed to work properly. Assuming all components are working properly, and setup is correct, any given adjustment recommendations are the proper adjustments to make.

4.6 User Error

Sometimes user error can occur. Most systems include printers to print out required adjustments, or at least have the option of printer hookup. Printers are highly recommended for use with RT&B equipment. The sequence from when the equipment determines the proper adjustments to make, relays this information to the mechanic, and then the mechanic actually makes the required adjustments may seem trivial, but it is very important that this sequence is performed error-free. If the system does not have a printer to print out required adjustments, it is common for the mechanic to write the required adjustments on his or her hand for example. Addition or subtraction of weight, extension or compression of pitch links, or movement of a trim tab are all indicated by a

+ or -. If these crucial signs are smudged on a hand, and a + is interpreted as a -, then obviously the process will fail. Also, even if the correct adjustments are acknowledged, mistakes can still be made. It is not always immediately obvious which way the pitch link turnbuckle should be rotated to achieve the desired effect. A very easy mistake to make is to

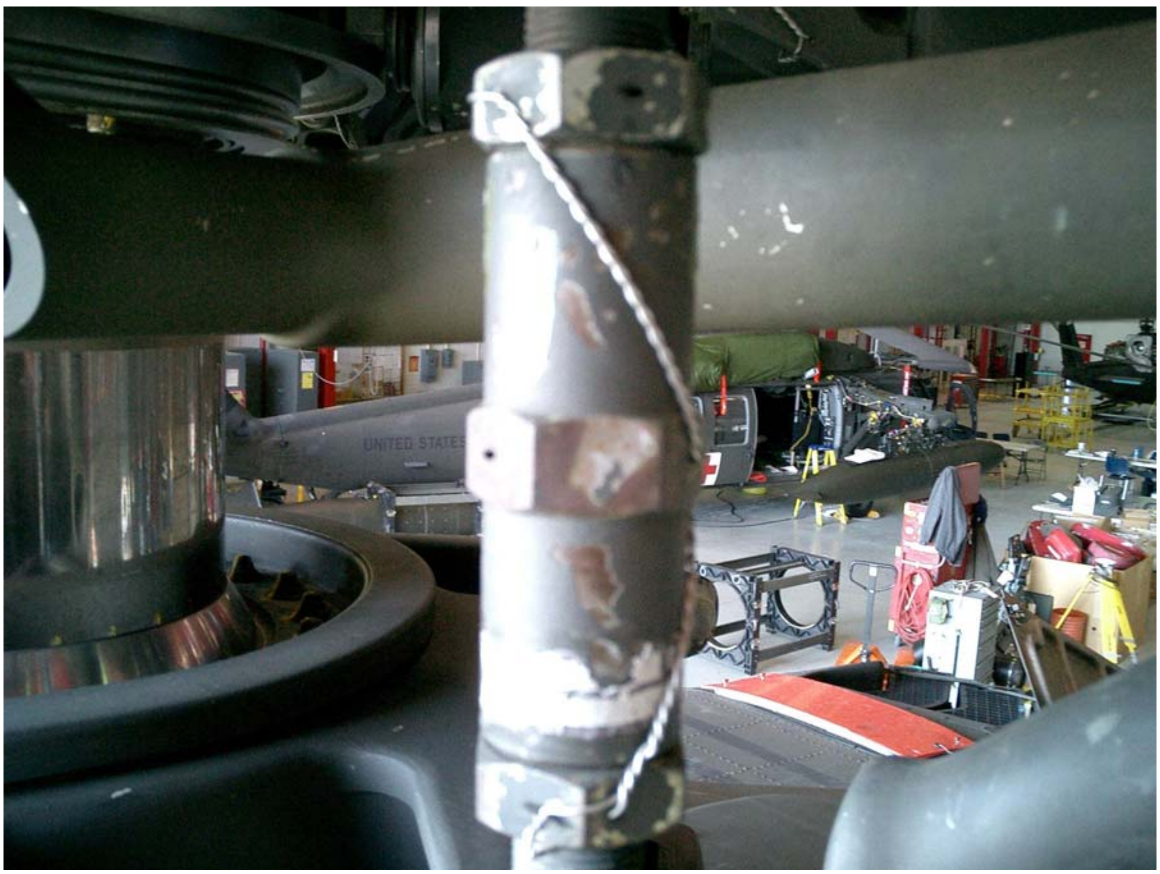


Figure 30. U.S. Army AH-64 Apache adjustable pitch link design

accidentally rotate the pitch link turnbuckle the wrong way, leading to smoothing failure. [Bale, 2004] Proper training can help reduce the chance of mechanic error. Figure 30

and 31 show two different pitch link designs. Figure 30 shows a AH-64 Apache pitch link, designed by McDonnell Douglas. The adjustment increment used is a "flat." The

Figure 31. U.S. Army UH-60 Black Hawk Adjustable Pitch Link Design

pitch link has a hexagon perimeter in the center, with the algorithm telling the mechanic how many of these "flats" to rotate and which direction. Using flats as a reference can be vague, especially when dealing with fractions of flats, where the rotation amount is really left to the interpretation of the mechanic.

A much better design is found on the Sikorsky H-60. Figure 31 shows the design of an adjustable pitch link found on the H-60. Instead of using "flats" as a rotation reference, Sikorsky uses notches located around the perimeter of the pitch link, secured

from rotation with a cotter pin. This style design removes all the guess work from the adjustment. All recommendations are given with a definite number of notches to rotate the turnbuckle. This type of "foolproof" design is what manufacturers should be aiming for in their designs.

4.7 Learning Algorithms

Aircraft are designed to be smoothable in every flight regime. Over time, however, some aircraft develop problems where they can no longer be smoothed in every regime. A compromise must be made when choosing which adjustments to make. The consensus is to concentrate on smoothing the flight regime used most by the aircraft.

Unexpected aircraft response is often attributed to fatigue and wear on the structure/components which changes the properties of the structure so that the structure no longer matches the original design specs. In these cases, smoothing may also be difficult because many system algorithms rely on data that was collected from the aircraft when it was new. So, gradually the actual aircraft will no longer match the model used by the RT&B algorithm and will not respond appropriately to any adjustments made. [Bale, 2004]

This is where the argument for a learning algorithm becomes strong. If the algorithm is tweaked with every iteration, any property changes to the airframe are compensated for. Initially, having a system that "learns" sounds like a great idea. The big disadvantage to the learning system comes when there is user error. If the smoothing equipment develops an adjustment or set of adjustments to be made, and the adjustments are made incorrectly (for example, moving a pitch link turnbuckle the wrong way by

accident), this can create some serious errors in the future performance of the algorithm. After an incorrect adjustment is made, assuming the user believes that he or she made the correct adjustment, when, for example, he or she made the opposite of the recommended adjustment, the algorithm will update its coefficients based on the response of the aircraft to the opposite of the indicated adjustments. Any future adjustment recommendations made by the algorithm will be made using the incorrect data input, rendering the algorithm corrupt. Indeed, the idea of a learning algorithm is promising. However, before this type of algorithm is implemented in the hands of the average maintenance technician, it must be deemed fool-proof first. An adjustment system must be designed in which it is impossible to make an incorrect move by mistake.

The ACES and DSS systems are learning systems geared towards the "seasoned pro" who is conscious about making correct moves every time. Plus, these systems only call for one adjustment per iteration, so if an incorrect move were made, it would be immediately obvious after the next test flight. However, while it is likely the user will recognize if he or she made an adjustment error, the algorithm will not, and the erroneous coefficient change cannot and will not be fixed. These companies should include an option to return the coefficients back to where they were before the previous iteration to allow for cases when the user recognizes an error. [Johnson, 2004]

In the case of a non-learning algorithm, the appropriate resolution for an aircraft which no longer responds to adjustments as it "should" or used to, is for a new script file to be written for that particular aircraft. The new script file will be specific to the aircraft compensating for any changes that have occurred in aircraft reponse behavior. [Bale, 2004]

4.8 HUMS

One improvement that is being instituted already is using permanently installed equipment on board the aircraft for RT&B, usually part of a HUMS. Having permanently installed equipment eliminates the need for the time consuming equipment hookups required with traditional systems. The rough, exposed wiring can also become a hazard, as the U.S. Navy has had at least one fatality from a crew member getting tangled up in the wiring during a smoothing session. [Brown, 2004] Permanently installed systems are also more reliable. The equipment components endure less abuse, not having to be installed and uninstalled at each smoothing. The connection wires will eventually become fatigued from repeated movement. So, clearly there is an advantage to permanently installed equipment, in time savings, safety, and reliability. Also, because the system is permanently installed, data can be collected at any time, so the system can give an early indication if a rotor smoothing is required. The disadvantage to the permanently installed system is that each helicopter requires its own system, adding to the cost of operating a fleet of helicopters.

4.9 Conclusions and Summary

Even with the best algorithm in the world (which many companies would claim of their own) the adjustments and test flight still must be done. The existing equipment and algorithms currently in use, do work. When used properly, they will all develop accurate solutions and allow smoothing to be achieved. The best possible case would be a complete solution with only one iteration. There are existing algorithms which are capable of only one iteration for a solution. It seems the majority of problems lie elsewhere. The major time consuming factors could be eliminated if improvements were

made in blade quality, rotor adjustment design, maintenance technician education, eliminating the possibility of user error, equipment reliability, moving towards permanently integrated systems, and developing "fool-proof" methods so that learning algorithms could be trusted. If money and R&D were to be put into the RT&B process, it should be spent trying to fix the problems outlined above rather than developing new algorithms.

APPENDIX A

The following Tables and Figures are the result of the 1973 Fort Eustis study.

COMPONENT COMPARISON OF RELIABILITY AND CORRECTIVE MAINTENANCE AT SUBSYSTEM LEVEL

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (w/o-w)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
Airframe																
Central Frames		5.0		83.2		2.6		6.1	2.4	77.1	190 - 350	40L + 40R	105 - 185	0.35/0.93	0.18/0.41	0.17/ 0.52
Engine Work Platform		9.6		62.8		9.3		14.6	0.3	48.2	190 - 245	35L + 40R	190 - 210	1.24/1.12	0.43/0.58	0.81/ 0.54
Transmission Work Platform		8.2		21.5		4.6		11.4	3.6	10.1	250 - 290	35L + 35R	190 - 210	1.32/1.19	0.44/0.53	0.88/ 0.66
Engine Fwd. Cowling		12.7		34.1		3.7		10.8	9.0	23.3	180 - 190	35L - 35R	190 - 210	0.95/1.11	0.43/0.49	0.52/ 0.62
Engine Aft Cowling		11.2		19.3		5.9		7.9	5.3	11.4	245 - 250	35L - 35R	190 - 210	1.22/1.42	0.46/0.59	0.66/ 0.83
APU Cowling		10.4		15.1		7.0		11.8	3.4	3.3	290 - 360	35L - 35R	190 - 225	1.33/1.63	0.45/0.57	0.88/ 1.06
M.R. Pylon Structure		8.2		17.2		3.6		6.1	4.6	11.1	250 - 290	35L - 35R	190 - 225	1.35/1.67	0.45/0.54	0.90/ 1.13
Access Panels		7.5		17.0		3.6		5.6	3.9	11.4	290 - 360	35L - 35R	190 - 225	1.33/1.63	0.45/0.57	0.88/ 1.06
Sponson Skin		6.7		16.5		1.0		2.9	5.7	13.6	265 - 400	45-95L + 45-95R	80 - 115	0.12/0.35	0.10/0.21	0.02/ 0.14
Aft Ramp		5.0		16.2		1.3		4.6	3.7	11.6	450 - 540	40L - 40R	100 - 145	0.25/0.71	0.15/0.54	0.10/ 0.17
M.R. Pylon Fairing		6.4		11.0		0		0	6.4	11.0	250 - 290	35L - 35R	190 - 225	1.35/1.67	0.45/0.54	0.90/ 1.13
All Other Airframe Systems		132.8		278.4		65.2		127.9	77.6	150.5	--	--	--	0.97/1.23(Av)	0.36/0.49(Av)	
Drive																
M.G.B. Press. Transmitter		5.4		6.3		0.7		0.8	4.7	5.5	260	0	190	1.35	0.49	0.86
M.G.B. Rot. Br. Cyl.		7.7		29.0		2.6		11.7	5.1	17.3	260	0	190	1.35	0.49	0.86
M.G.B. Lubelines		7.2		12.6		3.4		3.5	3.8	9.1	245 - 330	35L - 35R	190 - 210	1.15/1.49	0.51/0.58	0.64/ 0.91
M.G.B. Torque Transmitter		10.1		16.2		1.1		1.2	9.0	15.0	245	15L + 15R	200	1.40/1.33	0.59/0.56	0.81/ 0.87
APU Clutch		9.2		50.0		4.6		34.8	4.6	15.2	295	20L	195	1.49	0.47	1.02
Main Gearbox		2.9		87.6		2.0		90.0	0.9	-2.4	245 - 290	30L - 30R	185 - 215	1.39/1.76	0.50/0.56	0.89/ 1.20
M.G.B. Seals		2.2		22.7		0.3		1.4	1.9	21.3	245 - 290	20L - 20R	185 - 215	1.40/1.77	0.51/0.56	0.89/ 1.21
M.G.B. Flexible Hoses		4.2		19.3		0.5		0.8	3.7	18.5	240,270 -300	35R -20L	200	1.38/1.46	0.49/0.55	0.89/ 0.81
All Other Drive Systems		59.8		128.1		32.4		72.3	27.4	55.8				1.36/1.56(Av)	0.50/0.56(Av	

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (w/o-w)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
Utility																
Cargo/Rescue Hook		7.4		7.6		1.1		2.6	6.3	5.0	120-140	0 - 30R	115 - 170	0.36/0.86	0.26/0.42	0.10/0.44
Hoses, Lines, Tubes		7.2		11.1		0.3		0.3	6.9	10.8	180-350	35L-35R	80 - 220	0.16/1.82	0.11/0.58	0.05/1.24
Fire Sensing Element		5.5		18.5		1.3		1.0	4.2	17.5	180-340	30L-30R	185 - 210	1.05/1.63	0.42/0.52	0.63/1.11
Fire Detector Control		4.1		7.1		0.6		1.0	3.5	6.1	180 - 340	30L - 30R	185 - 210	1.05/1.63	0.42/0.52	0.63/1.11
Switches-Cargo		3.6		22.1		3.2		18.8	0.4	2.3	120-140	0 - 30R	115 + 170	0.36/0.86	0.26/0.42	0.10/0.44
Valves-Cargo/Rescue		2.6		5.7		0.2		0.2	2.4	5.5	120 - 140	0 - 30R	115 + 170	0.36/0.86	0.26/0.42	0.10/0.44
All Other Utility		33.7		34.3		7.1		2.4	26.6	31.9				0.56/1.28(Av)	0.29/0.48(Av)	
Landing Gear																
Nose Landing Gear Shock		2.0		76.0		2.0		25.5	3.4	40.5	130	0	80 - 120	0.14/0.39	0.22/0.42	0.08/0.03
Kneeling Valve		6.6		23.9		1.6		6.0	5.0	17.9	270	20R	190	1.37	0.50	0.87
M.L.G. Wheel		7.2		14.3		0		0	7.2	14.3	340	75±85L 75±85R	70	0.06/0.17	0.11/0.14	0.05/0.03
M.L.G. Actuating Cylinder		5.1		22.4		2.4		15.2	2.7	7.2	310 - 320	80L + 80R	95 - 100	0.27/0.33	0.10/0.24	0.17/0.09
M.L.G. Scissors		3.7		8.5		1.3		1.6	2.4	6.9	290-340	80L + 80R	70 - 110	0.21/0.39	0.22/0.30	0.01/0.09
All Other Landing Gear		63.5		154.5		37.5		141.5	26.0	13.0				0.41/0.32(Av)	0.23/0.28(Av)	
Lights(*)(See Detailed Tabulation for Lights Table VI, and Figure 29)																
Emergency Exit		22.2		19.4		7.8		6.3	14.4	13.1	230-485	40R - 30L	160-125	0.95/1.02	0.38/0.56	0.57/0.46
Position Lights		18.8		31.9		3.5		4.3	15.3	27.6	270, 320,730	90LR, 0,0	90, 125,280	0.26/1.39	0.19/0.63	0.07/0.76
Panel Lights		15.4		46.8		4.4		6.8	11.0	40.0	70	35L-35R	145	0.44	0.35	0.09
Anticollision Lights		10.3		19.5		2.1		2.5	8.2	17.0	355, 720	0,0	80, 230	0.31/1.90	0.11/0.97	0.20/0.93
Fuselage Lights		13.5		29.6		0.3		0.3	13.2	29.3	315, 320	0,0	80, 225	0.32/1.90	0.08/0.97	0.24/0.93
All Other Lights		39.4		93.5		11.2		25.5	28.2	68.0	70 - 510	40L - 40R	80 - 190	0.44	0.35	0.09

COMPONENT NAME	WITHOUT ABSORBER (W/O) FAILURES	WITHOUT ABSORBER (W/O) FAILURE RATE (10^{-3})	WITHOUT ABSORBER (W/O) MMH	WITHOUT ABSORBER (W/O) MMH/KFH	WITH ABSORBER (W) FAILURES	WITH ABSORBER (W) FAILURE RATE (10^{-3})	WITH ABSORBER (W) MMH	WITH ABSORBER (W) MMH/KFH	Δ-(W/O-W) FAILURE RATE (10^{-3})	Δ-(W/O-W) MMH/KFH	LOCATION S.T.A.	LOCATION B.L.	LOCATION W.L.	G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (w/o-w)
<u>Fuel</u>																
Fuel Cells & Auxiliary Tanks		4.0		22.9		3.4		5.6	0.6	17.3	190-370	110L-110R	80 - 150	0.37/0.77	0.29/0.59	0.08/0.18
Hoses, Lines, Tubes		7.5		12.0		1.6		2.1	5.9	9.9	140-350	110L-110R	90 - 210	0.37/1.35	0.26/0.52	0.11/0.83
Indicator Sensors		7.5		14.5		1.6		3.5	5.9	11.0	190-370	35L - 35R	80 - 140	0.36/0.78	0.29/0.47	0.07/0.31
Press. Switches		4.7		8.8		1.5		1.1	3.2	7.7	240	0	200	1.48	0.60	0.88
All Other Fuel Components		32.5		60.6		14.7		38.5	17.8	22.1				0.65/0.78(Av)	0.36/0.53(av)	
<u>Flight Controls</u>																
Servos		15.5		88.5		3.7		7.3	11.8	81.2	250 - 290	20L-20R	200-210	1.49/1.67	0.51/0.59	0.98/1.08
Hose Lines		6.1		14.0		2.6		2.1	3.5	11.9	250 - 310	20L - 20R	190 - 210	1.56/1.72	0.51/0.59	1.05/1.13
Panel Package		4.4		8.7		0.6		0.8	3.8	7.9	90	0	120	0.47	0.28	0.19
Springs, Balance		2.8		11.6		1.3		6.1	1.5	6.5	110,70 695	40R, 30R,0	110, 115,210	0.31/x/1.56	0.31/x/0.84	0/0.7
Control Sticks		2.7		3.4		0.9		1.0	1.8	2.4	80 - 110	35L - 20R	120-140	0.35	0.30	0.05
Auxiliary Servos		2.5		4.4		0.4		1.3	2.1	3.1	130	30R	145	0.61	0.33	0.28
Stick Friction Lock		2.2		4.1		0.8		2.7	1.4	1.4	100	35L, 5R	130	0.38/0.42	0.29/0.30	0.09/0.12
Pressure Transmitter		1.9		5.0		0.3		0.2	1.6	4.8	310	20R	200	1.62	0.54	1.08
Control Rods		1.9		4.3		0		0	1.9	4.3	70-280	30L - 30R	115 - 190	0.33/1.22	0.19/0.43	0.14/0.79
All Other Flight Controls		18.4		65.5		12.2		39.0	6.2	26.5				0.79/1.32(Av)	0.36/0.55(Av)	
<u>Cockpit/Fuselage</u>																
Seats		11.2		17.4		2.6		9.4	8.6	8.0	110	30L - 30R	120-140	0.37/0.42	0.30/0.33	0.07/0.14
Panels		4.7		8.1		0.7		1.4	4.0	6.7	100-290	30L - 30R	170 - 180	0.55/1.11	0.34/0.41	0.21/0.70
Litter Accessory		2.4		2.7		0		0	2.4	2.7	170-460	40L - 40R	105 - 175	0.25/0.84	0.16/0.40	0.09/0.74
Floor		4.0		2.4		1.6		1.3	2.4	1.1	120 - 450	40L - 40R	105	0.22/0.32	0.16/0.29	0.06/0.03
Misc. Equipment		8.7		12.6		1.6		6.4	7.1	6.2	70 - 510	40L - 40R	105-180	0.30/0.92	0.29/0.56	0.01/0.36
All Other Cockpit		2.1		5.7		3.4		4.7	-1.3	1.1				0.34/0.73(Av)	0.25/0.40(av)	

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (w/o-w
	FAILURES	FAILURE RATE (10^{-3})	MMH	$\frac{MMH}{KFH}$	FAILURES	FAILURE RATE (10^{-3})	MMH	$\frac{MMH}{KFH}$	FAILURE RATE (10^{-3})	$\frac{MMH}{KFH}$	S.T.A.	B.L.	W.L.			
Electrical																
Generators		11.0		24.3		1.5		6.8	9.5	17.5	300	20L, 20R	205	1.66/1.68	0.49/0.45	1.17/ 1.23
Inverter		1.2		2.2		0.2		1.0	1.0	1.2	80	30L	90	0.28	0.31	0.03
Junction Box		1.4		1.3		0.8		0.5	0.6	0.8	70 - 320	35L, 35R	95 - 175	0.20/1.15	0.31/0.40	0.11/ 0.75
Battery		3.4		10.9		1.9		1.9	1.5	9.0	55	0	120	0.38	0.34	0.04
Circuit Breakers		1.6		5.6		0		0	1.6	5.6	100 - 110	30L - 40R	135 - 180	0.42/0.59	.0.33/0.36	0.09/ 0.23
Volt Regulator		1.4		4.6		0.8		0.9	0.6	3.7	150	40L	145	0.52	0.33	0.19
Transformer/Rectifier		2.4		8.4		0.8		1.0	1.6	7.4	110	30L	100	0.79	0.30	0.01
Engine Start Relay		2.4		4.9		1.4		0.6	1.0	4.3	120	0	115	0.36	0.29	0.07
All Other Electrical		10.8		17.2		6.0		13.5	4.8	3.7				0.51/1.14(Av)	0.34/0.40(Av)	
Hydraulic Power																
Flex Hoses, Tubes, Lines		10.3		11.2		4.2		4.7	6.1	7.0	115- 505	80L- 80R	90 - 210	0.27/1.35	0.29/0.56	0.02 0.7
Utility Panel Package		5.8		1.9		3.7		4.2	2.1	-2.3	300	30R	190	1.36	0.47	0.89
Pressure Transmitter		5.3		11.2		0.7		1.1	4.6	10.1	300	30R	190	1.36	0.47	0.89
Utility Pump		4.9		23.8		2.1		4.3	2.8	19.5	290	10L	205	1.71	0.59	1.12
Reservoir		3.7		3.1		2.4		1.6	1.3	1.5	310	10R	210	1.79	0.61	1.18
All Other Hydraulic		7.1		24.6		4.0		4.0	3.1	20.6				1.30/1.35(Av)	0.49/0.56(Av)	
Intercommunications																
Connectors/Plugs		12.85		24.5		9.9		20.3	2.9	4.2	140	35L	180	0.32/0.75	0.22/0.41	0.10/ .0.3
Cords/Jacks		9.3		22.8		3.4		14.4	5.9	8.4	90,130 180,340	0 20L 35L,40R	130,170 170,160	0.32/0.75	0.22/0.41	0.10/ 0.3
Control Panels		8.5		8.7		4.9		8.1	3.6	0.6	90,130 180,340	0 20L 35L, 40R	130,160 170,170	0.34/0.75	0.21/0.75	0.13/ 0
Set Controls		3.4		6.1		1.6		3.4	1.8	2.7	90	0	130	0.34	0.21	0.13
All Other ICS		6.5		9.1		2.4		3.5	4.1	5.6				0.33/0.75(Av)	0.22/0.52(Av)	

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (w/o-w)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
Radio/Navigation LF/ADF Rcvr. (ARN-59)		6.3		13.8		4.2		17.1	2.1	-3.3	130	30L	170	0.75	0.35	0.40
Tacan RT (ARN-65)		14.0		75.3		12.1		77.6	1.9	-2.3	90	0	90	0.22	0.29	0.07
Radio Nav/Rcvr. (ARN-58)		7.1		27.4		7.3		25.4	-0.2	2.0						
UHF/DF Amplifier (ARN-25)		3.7		7.8		4.7		11.3	-1.0	-3.5	100	25L	100	0.31	0.31	0
VOR 101 Rcvr.		4.0		9.2		7.3		28.1	-3.3	-18.9	110	35R	100	0.32	0.29	0.03
VOR 101 Instrumentation Unit		3.1		6.6		6.5		26.3	-3.4	-19.7	90	0	130	0.22	0.29	0.07
All Other Radio Nav.		27.3		68.9		8.1		31.9	19.2	37.0	90-180	30L - 30R	100	0.22/0.75 0.34/0.75(Av)	0.29/0.51 0.30/0.51(Av)	0.07/0.24
Airconditioning/Heating Ducting		12.0		46.1		1.0		1.4	11.0	44.7	60-480	35L-35R	115-175	0.32/1.30	0.22/0.52	0.10/0.78
Ignition Unit		0.8		5.0		5.0		15.3	-4.2	-10.3	100	40R	135	1.20	0.48	0.72
Blower		3.4		20.5		0.3		1.6	3.1	18.9	520	10R	170	1.20	0.48	0.72
Controls		2.6		5.5		1.8		5.9	0.8	-0.4	110	0	180	0.32	0.22	0.10
Electrical		8.3		18.6		10.2		11.9	-1.9	6.7	440, 445, 110	35L, 0, 35R	105, 170, 110	0.67 0.74/1.30(Av)	0.41 0.36/0.52(Av)	0.26

Minus Sign indicates increase in maintenance or failure rate.

COMPONENT COMPARISON OF RELIABILITY AND CORRECTIVE MAINTENANCE - INTERNAL AND EXTERNAL LIGHTS

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (w/o-w)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
Exterior Lights																
Controllable Spotlight	9	1.45	10.6	1.70	7	1.13	6.0	0.97	0.32	0.73	45	0	130	0.33	0.32	0.01
Exterior Lights (Gen.)	10	1.61	27.2	4.37	0	0	0	0	1.61	4.37	45-725	0-95	80-235	0.40	0.32	0.08
Position Lights	117	18.77	198.8	31.92	22	3.57	26.5	4.29	15.20	27.63	310	95	90	0.33	0.07	0.26
Anticollision Light	64	10.28	121.5	19.51	13	2.11	15.5	2.51	8.17	17.00	250/720	0/0	80/275	0.08/1.9	0.11/0.97	0.03/
Fuselage Lights	84	13.47	184.4	29.61	2	0.32	2.0	0.32	13.15	29.29	315/720	0/0	80/225	.05/1.9	0.08/0.97	0.03/
Anchor Lights	11	1.77	25.2	4.05	10	1.62	11.0	1.78	0.15	2.27	50/725	0/0	140/235	.32/1.9	0.32/0.97	0.0/
Flood Lights	36	5.78	62.0	9.95	15	2.43	27.0	4.38	3.35	5.57	45/310	0/70LR	105/80	.36/.06	0.35/0.09	0.01/
Landing Lights	41	6.58	121.9	19.57	9	1.46	56.0	9.07	5.12	10.50	75	0	85	0.28	0.09	0.19
Control Searchlight	45	7.22	125.5	20.15	17	2.75	43.6	7.07	4.47	13.08	95	0	80	0.29	0.09	0.20
Loading Light	1	0.16	0.5	0.08	0	0	0	0	0.08	0.08	380/550	0/0	180/145	1.3/0.9	0.52/0.58	0.78/
Internal Lights																
Internal Lights General	58	9.31	127.3	20.44	9	1.62	12.3	1.99	7.69	18.45	140-485	0.90R	145-185	.75/1.02	0.34/0.56	0.41/
Dome Lights	13	2.08	27.1	4.35	0	0	0	0	2.08	4.35	396	0	180	1.27	0.49	0.73
Cockpit Spotlight	14	2.25	39.2	6.29	1	0.16	1.0	0.16	2.09	6.13	110	0	185	0.69	0.36	0.33
Panel Light	96	15.41	291.6	46.82	27	4.37	41.9	6.78	11.04	40.04	70	20LR	145	0.44	0.35	0.09
Emergency Exit Light	138	22.16	120.9	19.41	48	7.79	38.6	6.25	14.37	13.16	230/485	40R/30LR	160/165	.95/1.02	0.38/0.56	0.57/
Signal Light	8	1.28	15.3	2.46	0	0	0	0	1.28	2.46	140	40R	160	0.59	0.36	0.23

COMPONENT COMPARISON OF RELIABILITY AND CORRECTIVE MAINTENANCE - SWITCHES

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (w/o-w)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
Ramp	26	4.17	55.5	8.91	14	2.26	22.2	3.59	1.91	5.32	250	25R	150	.82	.34	0.48
Nose Gear Kneeling	3	.48	5.1	.82	2	.32	2.5	.41	0.16	0.41	100	0	0	.61	.35	0.26
Nose Gear Up Limit	7	1.12	13.6	2.18	1	.16	1.2	.19	0.96	1.99	130	0	100	.30	.26	0.04
M.G. Down Limit	9	1.44	29.2	4.69	2	.32	2.5	.41	1.12	4.28	340	80^{L}_{R}	90	.28/.38	.18/.20	0.10/
M.G. Lock Limit	17	2.73	60.1	9.65	2	.32	7.0	1.13	2.41	8.52	340	80^{L}_{R}	90	.28/.37	.18/.20	0.10/
M.G. Uplock Limit	9	1.44	53.7	8.62	3	.48	22.0	3.57	0.96	5.05	340	80^{L}_{R}	90	.28/.37	.18/.20	0.10/
M.G. Speed	21	3.37	79.1	12.70	6	.97	11.5	1.86	2.40	1.20	100	0	175	.61	.35	0.26
Auxiliary Servo Cylinder	11	1.77	34.2	5.49	18	2.92	32.9	5.33	-1.15	0.16	90	035L	135	.41	.32	0.09
Auxiliary Servo Cylinder Pressure	12	1.93	27.3	4.38	2	.32	1.3	.21	1.61	4.17	300	10R	190	1.56	.53	1.03
M.G.B. Pressure	24	3.85	72.1	11.58	6	.97	3.8	.62	2.88	10.96	300	10R	190	1.56	.53	1.03
Brake Pressure	17	2.73	61.3	9.84	8	1.29	6.3	1.02	1.44	8.82	300	10R	190	1.56	.53	1.03
Heater Thermal	2	.32	15.5	2.49	0	0	0	0	0.32	2.49	470	0	170	1.36	.52	0.84
Heater Blower	1	.16	63	1.01	0	0	0	0	0.16	1.01	470	0	170	1.36	.52	0.84
Heater Control	0	0	0	0	1	.16	4.0	.65	-0.16	-0.65	470	0	170	1.36	.52	0.84
Windshield, Anti-Ice	1	.16	20	3.21	2	.32	3.5	.57	-0.16	2.61	110	0	175	0.60	.34	0.26
Engine Anti-Ice	5	.80	14.2	2.28	1	.16	5.0	.81	0.64	1.47	110	0	175	0.60	.34	0.26
Power Control, Battery	1	.16	2.0	.32	0	.0	0	0	0.16	0.32	100	0	175	0.61	.35	0.26
Generator	0	0	0	0	1	.16	3	.48	-0.16	-0.48	100	0	175	0.61	.35	0.26
Inverter	0	0	0	0	0	0	0	0	0	0	100	0	175	0.61	.35	0.26
External Power	0	0	0	0	0	0	0	0	0	0	100	0	175	0.61	.35	0.26
Volt Selector	0	0	0	0	0	0	0	0	0	0	100	0	175	0.61	.35	0.26
Transformer Rectifier	4	.64	3.3	.53	0	0	0	0	0.64	0.53	100	0	175	0.61	.35	0.26
Fuel Press.	24	3.85	54.0	8.67	2	.32	2.5	.41	3.53	8.35	240	0	200	1.48	.60	0.88
Internal Aux. Fuel Jettison	3	.48	3.0	.48	4	.64	2.0	.32	-0.16	0.16	270	0	160	1.12	.42	0.70
Aux. Fuel	12	1.93	20.3	3.26	3	.48	3.5	.57	1.45	2.69	110	0	160	.42	.33	0.09
Extinguisher	2	.32	7.0	1.12	1	.16	2.0	.32	0.16	0.80	95	0	175	.61	.35	0.26
Windshield Wiper	1	.16	2.0	.32	0	0	0	0	0.16	0.32	100	0	175	.61	.35	0.26
Rescue Hoist, Mode Selector	3	.48	1.4	.22	0	0	0	0	0.48	0.22	100	0	175	.61	.35	0.26
Hoist	13	2.08	22.1	3.55	10	1.62	5.9	.96	0.46	2.59	130	20R	175	.68	.38	0.30
Shear Test	8	1.28	9.2	1.48	13	2.11	8.1	1.31	-0.20	0.37	180	40R	175	.74	.37	0.37
Free Wheel	2	.32	1.2	.19	1	.16	4.0	.65	0.16	-0.46	100	0	175	.61	.35	0.26

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (W/O-W)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
Cargo Sling	1	.16	0.5	.08	0	0	0	0	0.16	0.08	100	0	175	.61	.35	0.26
Cargo	1	.16	2.5	.40	0	0	0	0	0.16	0.40	100	0	175	.61	.35	0.26
	240	38.49		108.47		16.62		25.39								

COMPONENT COMPARISON OF RELIABILITY AND CORRECTIVE MAINTENANCE - CONNECTORS/PLUGS/WIRING

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (W/O-W)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
Engine Wiring Harness	26	4.17	38.6	6.19	4	.65	5.5	.89	3.52	5.54	200	20LR	200	1.18/1.13	0.49/0.49	0.69/0.64
APU Wiring Harness	17	2.73	47.8	7.18	2	.32	1.8	.29	2.41	7.39	330	20L	195	1.38	0.51	0.87
AFCS Connector/Plug/Wiring	30	4.82	25.7	4.13	0	0	0	0	4.82	4.13	105	0	105	.32	0.29	0.03
HF Connectur/Plug/Wiring	9	1.45	5.9	.95	4	.65	5.5	.89	0.80	0.30	130	25L	110	.32	0.28	0.04
VHF101 Connector/Plug/Wiring	1	.16	0.5	.08	0	0	0	0	0.16	0.08	130	25L	140	.49	0.31	0.18
ARC44 Connector/Plug/Wiring	1	.16	0.2	.03	1	.16	1.0	.16	0	-0.13	270	35R	180	1.14	0.43	0.71
622A FM Connector/Plug/Wiring	4	.64	20.4	3.28	1	.16	9.0	1.46	0.48	3.12	270	35R	180	1.14	0.43	0.71
UHF Arc 108 Connector/Plug/Wiring	3	.48	2.7	.43	2	.32	4.0	.65	0.16	0.12	85	0	90	0.26	0.32	-0.06
ARC-34C Connector/Plug/Wiring	35	5.62	42.1	6.76	12	1.94	18.0	2.92	3.68	3.84	85	0	90	0.26	0.32	-0.06
AIC-18 Connector/Plug/Wiring	80	12.85	152.8	24.53	61	9.88	123.6	20.30	2.97	4.23	140	35L	180	0.75	0.41	0.34
APX-64 Connector/Plug/Wiring	6	.96	13.5	2.17	1	.16	1.0	.16	0.80	2.01	120	0	110	0.73	0.32	0.41
AIC-13 Connector/Plug/Wiring	4	.64	15.5	2.48	4	.65	4.0	.65	-0.01	1.83	100	35L	100	0.30	0.29	0.01
UTH-5 Connector/Plug/Wiring	6	.96	9.0	1.45	5	.81	6.5	1.05	0.15	0.40	270	25L	200	1.15	0.43	0.72
ARA-25 Connector/Plug/Wiring	4	.64	2.8	.45	5	.81	11.5	1.86	-0.17	1.41	100	25L	100	0.31	0.31	0
ARN-59 Connector/Plug/Wiring	4	.64	37.1	5.96	3	.49	8.5	1.38	0.15	4.58	130	30L	170	0.75	0.35	0.40
ARN-65 Connector/Plug/Wiring	7	1.12	18.6	2.99	7	1.13	22.8	3.69	-0.01	-0.70	90	0	90	0.22	0.29	-0.07
J-4 Connector/Plug/Wiring	11	1.77	14.6	2.34	3	.49	2.5	.41	1.28	1.83	100	0	100	0.32	0.29	0.03
VOR-10 Connector/Plug/Wiring	8	1.28	36.9	5.92	2	.32	10.0	1.62	.96	4.30	110	35R	100	0.32	0.29	0.03

COMPONENT COMPARISON OF RELIABILITY AND CORRECTIVE MAINTENANCE - HOSES/LINES

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (w/o-w)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
Ramp Flex Hose	4	.67	6.2	.96	0	0	0	0	0.67	0.96	440	40LR	95	.28/.34	0.17/0.23	0.11/ 0.11
Aft Ramp Uplock	77	12.36	261.6	42.00	21	3.40	57.5	9.32	8.96	32.68	505	35LR	125	1.02	0.56	0.46
Landing Gear Kneeling	57	9.15	183.5	29.46	21	3.4	43.9	7.11	6.11	22.35	270	20R	200	1.11	0.54	0.57
Landing Gear Actuating (A)	52	8.35	55.1	8.85	23	3.73	21.5	3.48	4.52	5.37	330	80LR	85	.22/.23	.14/.21	0.08/ 0.02
Landing Gear Actuating	10	1.61	7.4	1.19	5	.81	4.5	.73	0.80	0.46	330	80LR	85	.22/.23	.14/.21	0.08/ 0.02
Landing Gear Misc. Line	28	4.49	32.5	5.22	1	.16	1.0	.16	4.33	5.05	330	80LR	85	.22/.23	.14/.21	0.08/ 0.02
Landing Gear Misc. Flex. Hose	8	1.28	5.1	.82	0	0	0	0	1.28	0.82	330 260	80LR	85	.22/.23	.14/.21	0.08/ 0.02
Primary Servo Flex Hose	43	6.90	81.9	13.15	6	.97	5.0	.81	5.93	12.34	280 260	10LR	205	1.56/1.72	0.57/0.56	0.99/ 1.16
Primary Servo Line	42	6.74	57.9	9.30	18	2.92	13.0	2.11	3.82	7.19	280 260	10LR	205	1.56/1.72	0.57/0.56	0.99/ 1.16
Main Rotor Head Flex Hose	0	0	0	0	17	2.75	14.0	2.27	-2.75	-2.27	285 255	15LR	235	2.03	0.69	1.34
Engine Front Frame Hose	3	.48	8.0	1.28	0	0	0	0	0.48	1.28	185 225	15LR	200	1.83	0.54	1.29
Engine Misc. Line	34	5.46	56.4	9.06	4	.65	9.5	1.46	4.81	7.60	185 225	15LR	200	1.83	0.54	1.29
APU Line	33	5.29	64.5	10.36	20	3.24	21.0	3.40	2.05	6.96	330	10L	195	1.39	0.49	0.90
APU Flex Hose	13	2.09	16.8	2.69	13	2.11	10.5	1.70	-0.02	0.99	330	10L	195	1.39	0.49	0.90

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (w/o-w)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
APU Fuel & Air	8	1,28	8.2	1.32	0	0	0	0	1.28	1.32	330	10L	195	1,39	0.49	0.90
MGB Line	124	19.91	229.8	36.89	45	7.29	50.0	8.10	11.62	28.79	250 290	15L	195	1,49	0.52	0.97
MGB Flex Hose	50	8.03	190.3	30.56	18	2.92	79.0	12.80	5.11	17.76	250 290	15L	195	1.49	0.52	0.97
MGB Oil Cooler Hose	27	4.34	63.9	10.26	1	.16	2.0	.32	4.18	9.94	330	0	200	1.72	0.55	1.17
Heater Tube	3	.48	7.4	1,20	1	.16	0.5	.08	0.32	1.12	70	25LR	145	0.45	0.33	0.12
Hydraulic Power External Coupling	13	2.09	18.0	2.89	3	.49	1.0	.16	1,60	2.73	295	0	190	1.64	0.53	1.11
Utility Hydraulic Flex Hose	86	13,81	115.2	18.49	32	5.19	44.5	7.21	8.62	11.28	305	10R	200	1.82	0.58	1.24
Utility Hydraulic Tube	65	10.44	245.4	39.43	16	2.59	13.5	2.19	7.85	37.24	305	10R	200	1,82	0.58	1,24
Fuel Line	43	6.90	79.8	12.81	10	1.62	9.1	1.47	5.28	12.81	200 235	40LR	110 200	.37/1.35	0.26/.52	0.11/ 0,73
Fuel Flex Hose	7	1.12	6.5	1.04	5	.81	2.0	.32	0.31	0.72	200 235	40LR	110 200	.37/1.35	0.26/.52	0.11/ 0.73
Aux. Fuel Flex Line (Internal)	2	.32	1.6	.26	0	0	0	0	0.32	0.26	200 335	35LR	130	.59	0.34	0.25
Aux. Fuel Flex Line (External)	8	1.28	8.6	1.38	0	0	0	0	1.28	1.38	300	90LR	100	.37	0,14	0.13
Aux. Fuel Tube (External)	4	.64	9.5	1.45	0	0	0	0	0.64	1.45	300	90LR	100	.37	0.14	0.13
Probe - Hose	12	1.93	23.9	3.84	5	.81	7.5	2.21	1.12	2.63	160	40R	95	.25	0.16	0.09
Probe - Tube	4	.64	3.7	.59	3	.49	1.6	.26	0.23	0.33	160	40R	95	.25	0.16	0.09
Fuel Quick Disconnect	2	.32	4.5	.72	0	0	0	0	0.32	0.72	160	40R	95	.25	0.16	0.09

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (W/O-W)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
APU Fuel & Air	8	1.28	8.2	1.32	0	0	0	0	1.28	1.32	330	10L	195	1.39	0.49	0.90
MGB Line	124	19.91	229.8	36.89	45	7.29	50.0	8.10	11.62	28.79	250 290	15L	195	1.49	0.52	0.97
MGB Flex Hose	50	8.03	190.3	30.56	18	2.92	79.0	12.80	5.11	17.76	250 290	15L	195	1.49	0.52	0.97
MGB Oil Cooler Hose	27	4.34	63.9	10.26	1	.16	2.0	.32	4.18	9.94	330	0	200	1.72	0.55	1.17
Heater Tube	3	.48	7.4	1.20	1	.16	0.5	.08	0.32	1.12	70	25LR	145	0.45	0.33	0.12
Hydraulic Power External Coupling	13	2.09	18.0	2.89	3	.49	1.0	.16	1.60	2.73	295	0	190	1.64	0.53	1.11
Utility Hydraulic Flex Hose	86	13.81	115.2	18.49	32	5.19	44.5	7.21	8.62	11.28	305	10R	200	1.82	0.58	1.24
Utility Hydraulic Tube	65	10.44	245.4	39.43	16	2.59	13.5	2.19	7.85	37.24	305	10R	200	1.82	0.58	1.24
Fuel Line	43	6.90	79.8	12.81	10	1.62	9.1	1.47	5.28	12.81	200 235	40LR	110 200	.37/1.35	0.26/.52	0.11/ 0.73
Fuel Flex Hose	7	1.12	6.5	1.04	5	.81	2.0	.32	0.31	0.72	200 235	40LR	110 200	.37/1.35	0.26/.52	0.11/ 0.73
Aux. Fuel Flex Line (Internal)	2	.32	1.6	.26	0	0	0	0	0.32	0.26	200 335	35LR	130	.59	0.34	0.25
Aux. Fuel Flex Line (External)	8	1.28	8.6	1.38	0	0	0	0	1.28	1.38	300	90LR	100	.37	0.14	0.13
Aux. Fuel Tube (External)	4	.64	9.5	1.45	0	0	0	0	0.64	1.45	300	90LR	100	.37	0.14	0.13
Probe - Hose	12	1.93	23.9	3.84	5	.81	7.5	2.21	1.12	2.63	160	40R	95	.25	0.16	0.09
Probe - Tube	4	.64	3.7	.59	3	.49	1.6	.26	0.23	0.33	160	40R	95	.25	0.16	0.09
Fuel Quick Disconnect	2	.32	4.5	.72	0	0	0	0	0.32	0.72	160	40R	95	.25	0.16	0.09

COMPONENT COMPARISON OF RELIABILITY AND CORRECTIVE MAINTENANCE - VALUES

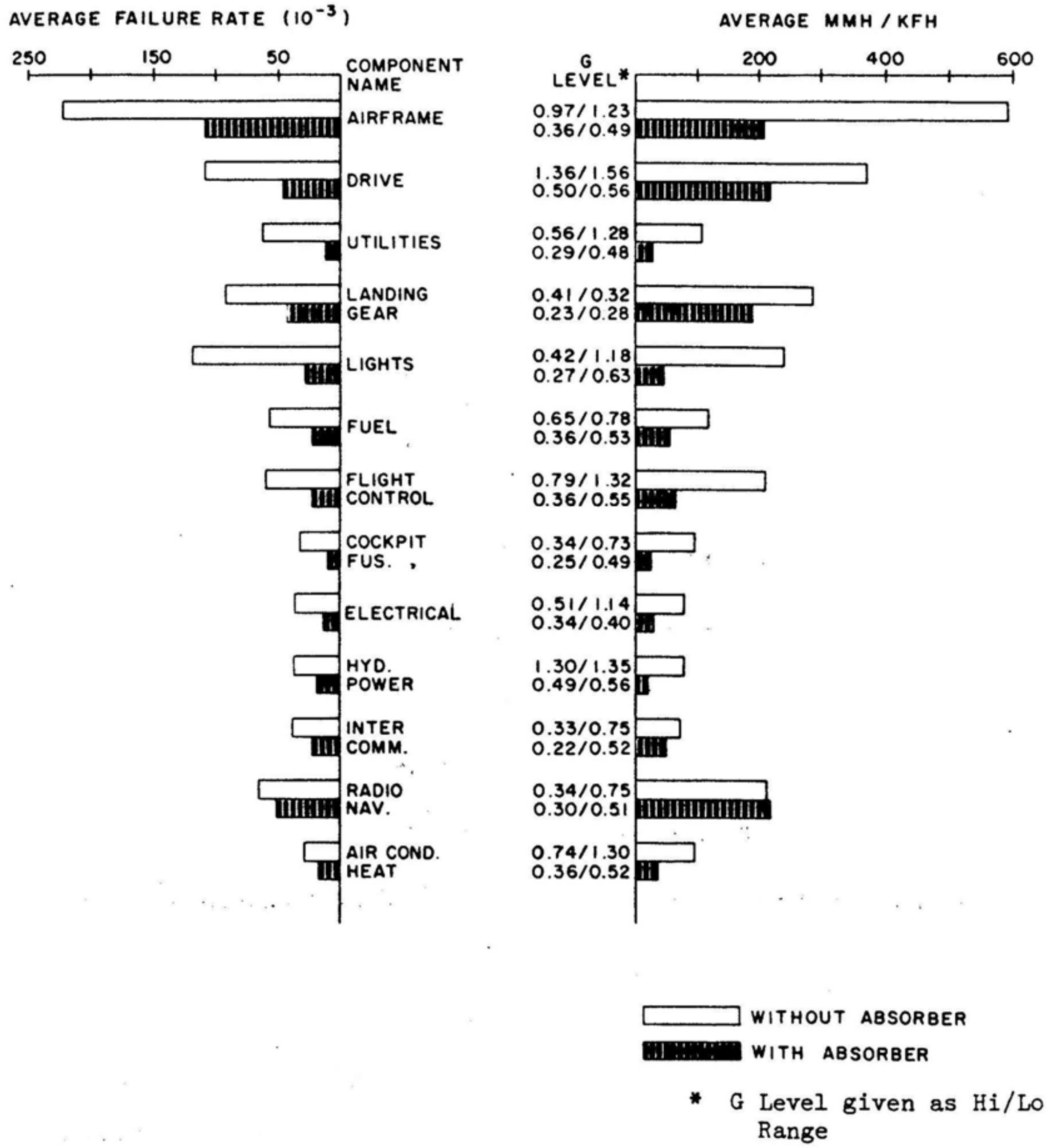
COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.		
Ramp Control	22	3.53	25.2	4.05	19	3.08	19.8	3.21	0.45	0.97	395	40R	140	0.58	0.32
Ramp Relief	0	0	0	0	1	.16	2.0	0.32	-0.16	-0.32	430	40R	160	0.83	0.39
Ramp Shuttle	1	.16	0.2	.03	0	0	0	0	0.16	0.03	395	40R	140	0.58	0.32
Ramp Shutoff	1	.16	2.0	.32	0	0	0	0	0.16	0.32	430	40R	160	0.83	0.39
Nose Gear Accumulator Emergency Release	6	.96	19.7	3.16	2	.32	1.5	0.24	0.64	2.84	320	13L	195	1.21	0.53
N.L.G. Press Lock	5	.80	30.7	4.93	3	.48	18.0	2.92	0.32	2.01	120	0	120	0.41	0.30
N.L.G. Check	8	1.28	27.8	4.46	1	.16	2.0	0.32	1.12	4.14	120	0	110	0.34	0.28
N.L.G. Shuttle	9	1.45	40.0	6.42	1	.16	0.5	0.08	1.29	6.34	120	0	110	0.34	0.28
N.L.G. Emergency Release	7	1.12	22.5	3.61	1	.16	1.0	0.16	0.96	3.45	320	13L	195	1.21	0.53
N.L.G. Thermal Relief	1	.16	4.0	.64	1	.16	4.0	0.64	0	0	120	0	110	0.34	0.28
N.L.G. Kneeling Control	64	10.28	280.1	44.97	12	1.94	46.0	7.45	8.34	37.52	270	20R	190	1.34	0.47
M.L.G. Package Brake	7	1.12	62.8	10.08	7	1.13	37.0	5.99	-0.01	4.09	70	20L,R	115	0.34/0.35	0.32/0.33
M.L.G. Mixer	10	1.60	35.8	5.75	0	0	0	0	1.60	5.75	265	16R	185	1.33	0.53
M.L.G. Emergency Release	1	.16	9.0	1.45	2	.32	1.15	0.24	-0.16	1.21	265	16R	185	1.33	0.53
M.L.G. Emergency Air Release	1	.16	0.6	.10	1	.32	0.5	0.08	-0.16	0.02	240	20R	190	1.25	0.48
Brake Bleed	12	1.93	71.7	11.51	3	.48	28.0	4.54	1.45	6.97	340	80L,R	70	0.28/0.37	.18/.20
Primary Control Shutoff	5	.80	9.8	1.57	0	0	0	0	0.80	1.57	310	10R	200	1.86	0.57
Primary Control Check	31	4.98	80.1	12.86	0	0	0	0	4.98	12.86	310	10R	200	1.86	0.57
Engine Relief	0	0	0	0	1	.16	2.0	.32	-0.16	-0.32	210	30L,R	200	1.48/1.41	0.48/0.47
Engine Bleed	30	4.82	24.8	3.98	2	.32	1.0	.16	4.50	3.82	210	30L,R	200	1.48.1.41	0.48/0.47
Fuel, Pilot	6	.96	13.0	2.09	2	.32	1.0	.16	0.64	0.93	210	30L,R	200	1.48/1.41	0.48/0.47
APU Shutoff	8	1.28	12.4	1.99	1	.16	2.0	.32	1.12	1.67	285	40L	115	0.44	0.24
APU Air Starter	2	.32	3.5	.56	6	.97	4.0	.65	-0.65	0.09	310	20L	200	1.56	0.52
MGB Drain	3	.48	1.4	.22	1	.16	6.0	.97	0.32	0.75	270	0	200	1.59	0.59
MGB Crossfeed	1	.16	3.6	.58	0	0	0	0	0.16	0.58	270	0	200	1.59	0.59
MGB Relief	6	.96	7.4	1.19	2	.32	2	.32	0.64	0.87	270	0	200	1.59	0.59
Oil Cooler Thermo, Relief	2	.32	10.0	1.61	0	0	0	0	0.32	1.61	330	0	200	1.73	0.52
Heater Fuel	8	1.28	7.3	1.17	1	.16	0.5	.08	1.12	1.09	170	40L	100	0.24	0.23
Heater Solenoid	7	1.12	5.2	.83	7	1.13	7.1	1.15	-0.01	-0.32	400	10L	170	0.67	0.41
Hot Air Inlet Check	0	0	0	0	3	.49	43.0	6.97	-0.49	-6.97	510	15R	170	1.02	0.56
Fuel Crossfeed	12	1.93	18.1	2.91	3	.49	2.5	.41	1.44	2.50	220	0	190	1.23	0.52

COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (W/O-W)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
Ramp Flex Hose	4	.67	6.2	.96	0	0	0	0	0.67	0.96	440	40LR	95	.28/.34	0.17/0.23	0.11/ 0.11
Aft Ramp Uplock	77	12.36	261.6	42.00	21	3.40	57.5	9.32	8.96	32.68	505	35LR	125	1.02	0.56	0.46
Landing Gear Kneeling	57	9.15	183.5	29.46	21	3.4	43.9	7.11	6.11	22.35	270	20R	200	1.11	0.54	0.57
Landing Gear Actuating (A)	52	8.35	55.1	8.85	23	3.73	21.5	3.48	4.52	5.37	330	80LR	85	.22/.23	.14/.21	0.08/ 0.02
Landing Gear Actuating	10	1.61	7.4	1.19	5	.81	4.5	.73	0.80	0.46	330	80LR	85	.22/.23	.14/.21	0.08/ 0.02
Landing Gear Misc. Line	28	4.49	32.5	5.22	1	.16	1.0	.16	4.33	5.05	330	80LR	85	.22/.23	.14/.21	0.08/ 0.02
Landing Gear Misc. Flex. Hose	8	1.28	5.1	.82	0	0	0	0	1.28	0.82	330 260	80LR	85	.22/.23	.14/.21	0.08/ 0.02
Primary Servo Flex Hose	43	6.90	81.9	13.15	6	.97	5.0	.81	5.93	12.34	280 260	10LR	205	1.56/1.72	0.57/0.56	0.99/ 1.16
Primary Servo Line	42	6.74	57.9	9.30	18	2.92	13.0	2.11	3.82	7.19	280 260	10LR	205	1.56/1.72	0.57/0.56	0.99/ 1.16
Main Rotor Head Flex Hose	0	0	0	0	17	2.75	14.0	2.27	-2.75	-2.27	285 255	15LR	235	2.03	0.69	1.34
Engine Front Frame Hose	3	.48	8.0	1.28	0	0	0	0	0.48	1.28	185 225	15LR	200	1.83	0.54	1.29
Engine Misc. Line	34	5.46	56.4	9.06	4	.65	9.5	1.46	4.81	7.60	185 225	15LR	200	1.83	0.54	1.29
APU Line	33	5.29	64.5	10.36	20	3.24	21.0	3.40	2.05	6.96	330	10L	195	1.39	0.49	0.90
APU Flex Hose	13	2.09	16.8	2.69	13	2.11	10.5	1.70	-0.02	0.99	330	10L	195	1.39	0.49	0.90

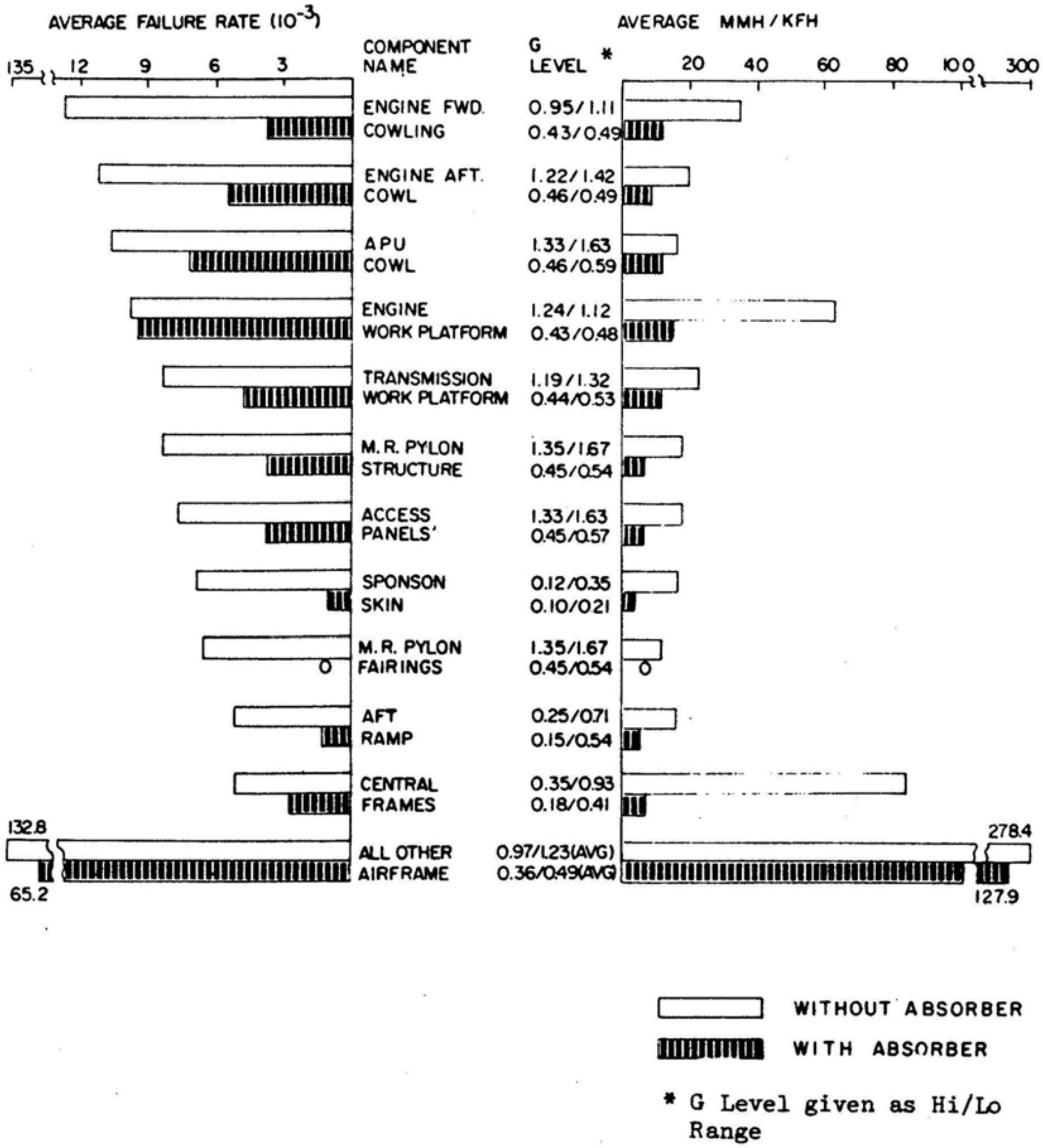
COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (w/o-w)
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
Fuel Shutoff	41	6.58	119.4	19.17	5	.81	34.2	5.54	5.77	13.63	170 260	0	90	0.27	0.24	0.03
Defueling	4	.64	7.5	1.20	0	0	0	0	0.64	1.20	210	40R	90	0.26	0.18	0.08
Sump Drain	10	1.60	22.5	3.61	0	0	0	0	1.61	3.61	200 330	0 0	80	0.22	0.17	0.05
Fuel Check	3	.48	2.4	.38	0	0	0	0	0.48	0.38	250	0	105	.38	.21	0.17
Flap	2	.32	5.0	.80	0	0	0	0	0.32	0.80	250	0	80	.06	.12	0.06
Manual Gate	1	.16	1.5	.24	0	0	0	0	0.16	0.24	220	40R	115	.39	.20	0.19
Fuel Bleed	2	.32	12.8	2.05	0	0	0	0	0.32	2.05	180 270	0	90	.17	.24	-0.07
High Level Shutoff	8	1.28	96.9	15.56	0	0	0	0	1.28	15.56	250	35L	100	.34	.26	0.08
Auxiliary Shutoff	4	.64	14.2	2.28	1	.16	5.0	.81	0.48	2.12	270	0	150	.69	.37	0.32
Relief	1	.16	8.0	1.28	0	0	0	0	0.16	1.28	225	0	90	.15	.15	0
Bleed Selector	12	1.93	52.1	8.37	2	.32	1	.16	1.31	8.05	240	0	200	1.25	.60	0.65
		58.39		187.98		14.84		44.21								

COMPONENT COMPARISON OF RELIABILITY AND CORRECTIVE MAINTENANCE - RELAYS

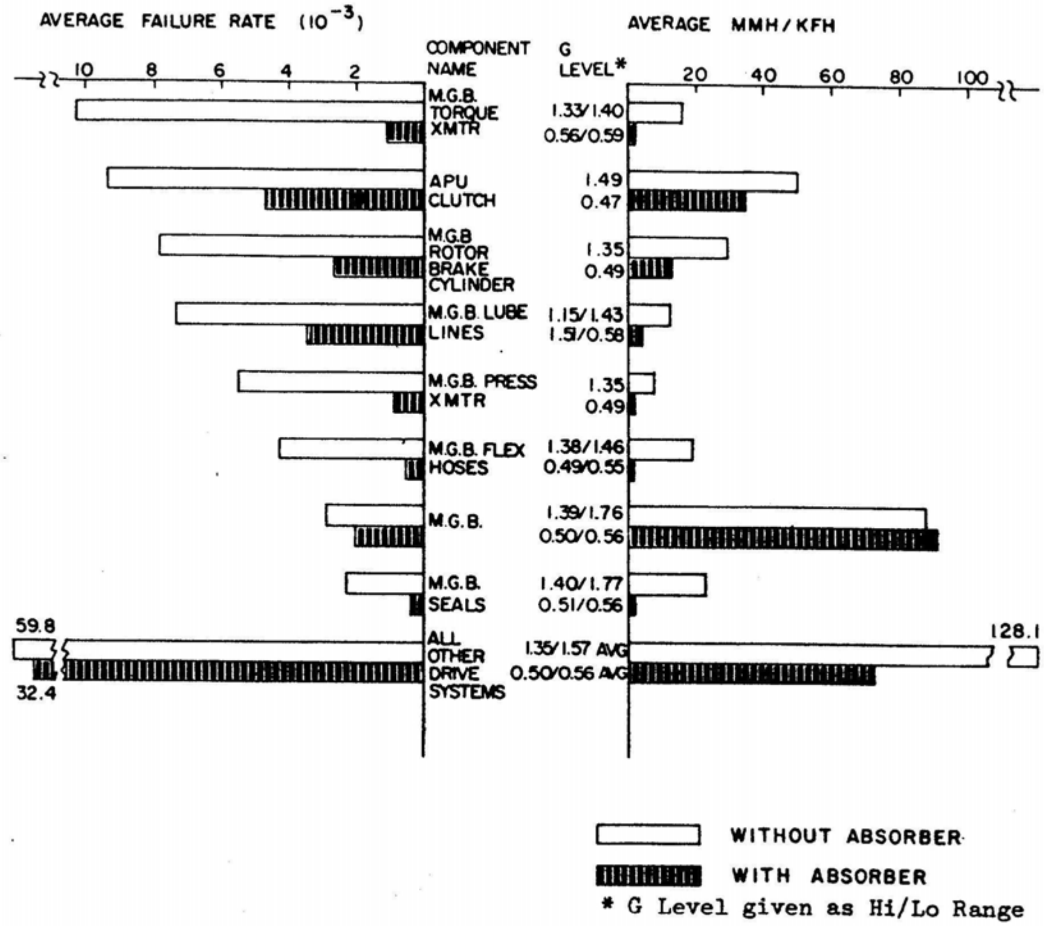
COMPONENT NAME	WITHOUT ABSORBER (W/O)				WITH ABSORBER (W)				Δ - (W/O-W)		LOCATION			G LEVEL WITHOUT ABSORBER	G LEVEL WITH ABSORBER	ΔG (w/o-w
	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURES	FAILURE RATE (10^{-3})	MMH	MMH/KFH	FAILURE RATE (10^{-3})	MMH/KFH	S.T.A.	B.L.	W.L.			
Engine Anti-Ice Relay	4	0.64	21.5	3.45	2	0.32	1.5	0.24	0.32	3.21	120	30L	170	0.61	0.34	0.27
Engine Anti-Ice Control Relay	9	1.45	38.2	6.13	2	0.32	3.0	0.49	1.13	5.64	100	0	185	0.66	0.36	0.30
Reverse Current Relay	13	2.09	54.2	8.70	16	2.59	41.3	6.69	-0.50	2.01	75	35L	100	0.31	0.29	0.02
Engine Start Relay	15	2.41	38.8	6.22	9	1.45	26.6	4.31	0.96	1.91	70	35LR	110	0.32	0.28	0.04
Generator Contractor	5	.80	8.5	1.36	0	0	0	0	0.80	1.36	75	35LR	110	0.32	0.28	0.04
Dimming Relay	6	.96	9.7	1.55	0	0	0	0	0.96	1.55	120	30L	170	0.61	0.34	0.27
Fuel Relay	7	1.12	21.9	3.51	1	.16	1.0	.16	0.96	3.35	120	30L	170	0.61	0.34	0.27
Rescue Hoist Relay	1	.16	15.8	2.53	0	0	0	0	0.16	2.53	115	10L	100	0.26	0.29	-0.03
VHF Power Relay	30	4.82	40.9	6.56	0	0	0	0	4.82	6.56	120	30L	170	0.61	0.34	0.27
ARA-25 Relay	6	.96	10.9	1.75	0	0	0	0	0.96	1.75	130	35L	125	0.42	0.31	0.11
		15.41		41.79		4.84		11.89								



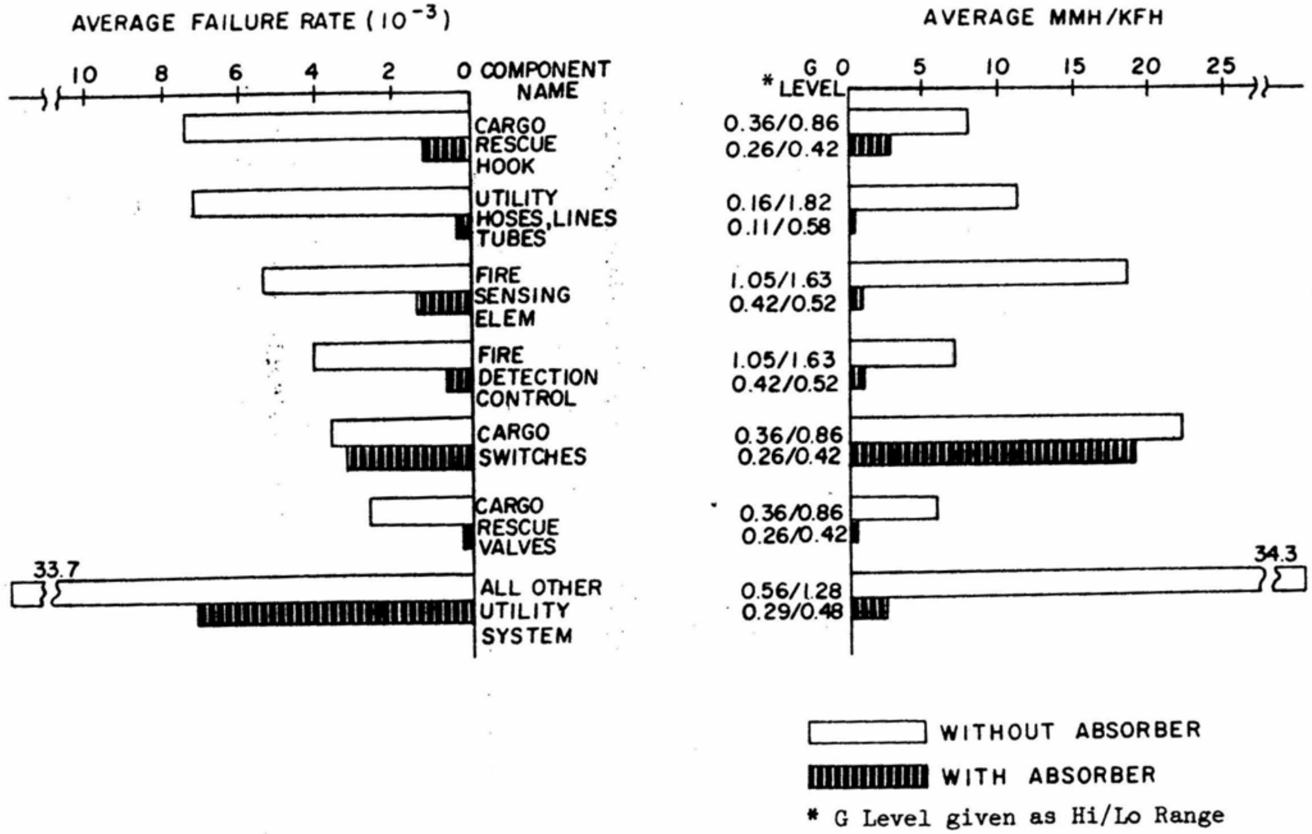
Comparison of Total Average Failure Rate and MMH/KFH for Top 13 Aircraft Subsystems.



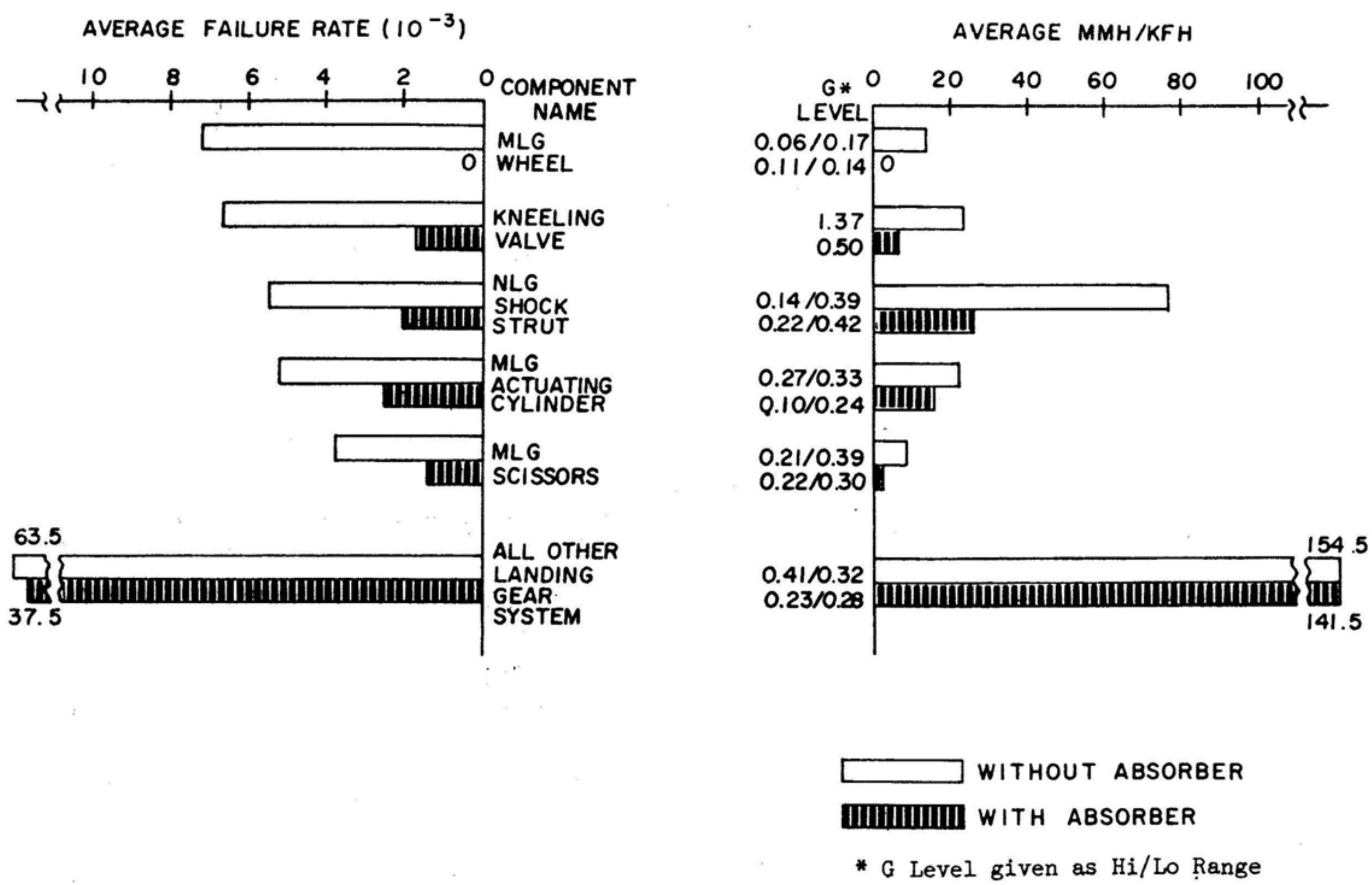
Comparison of Average Failure Rate and MMH/KFH
for Selected Airframe Subsystem Components.



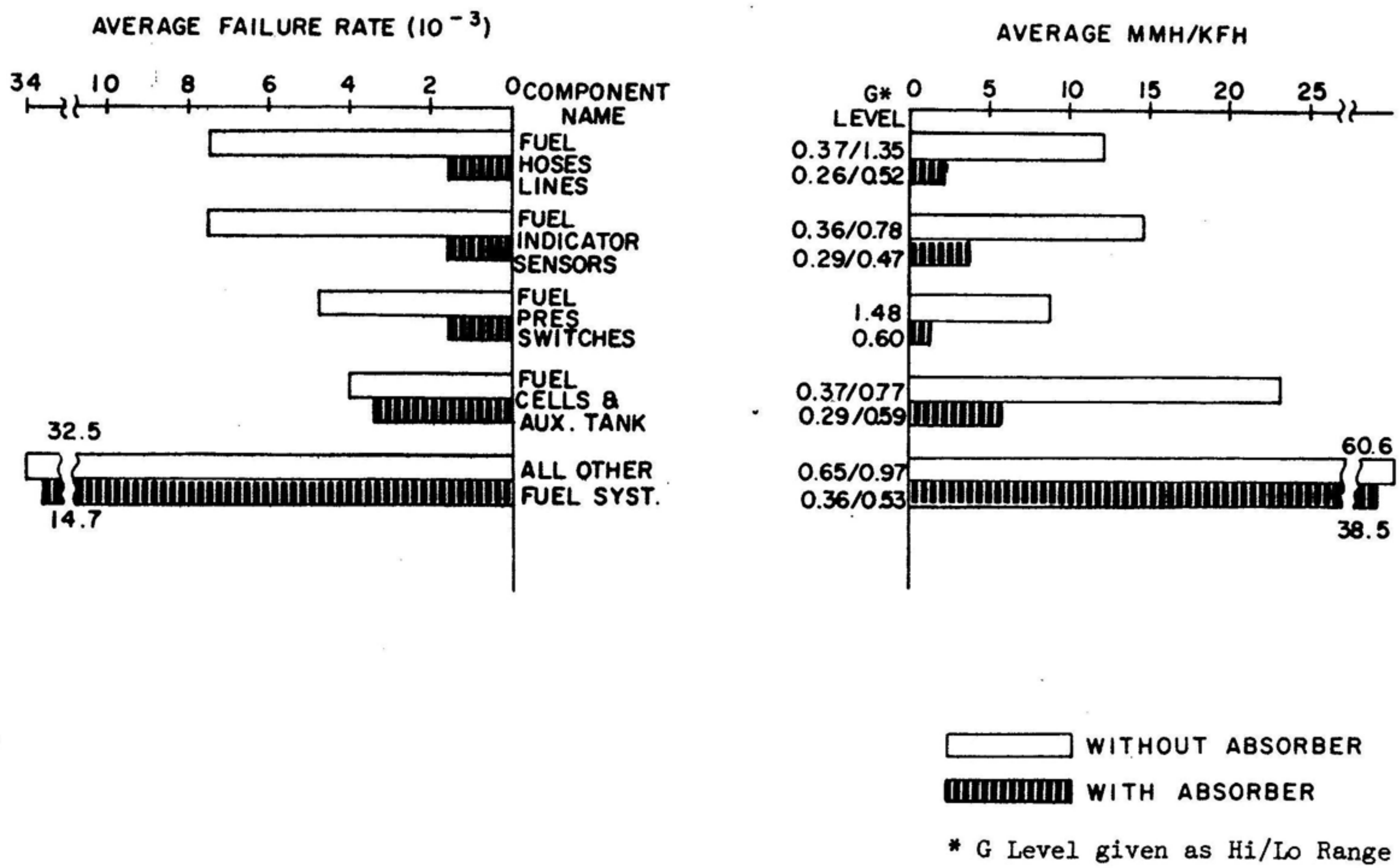
Comparison of Average Failure Rate and MMH/KFH for Selected Drive Subsystem Components.



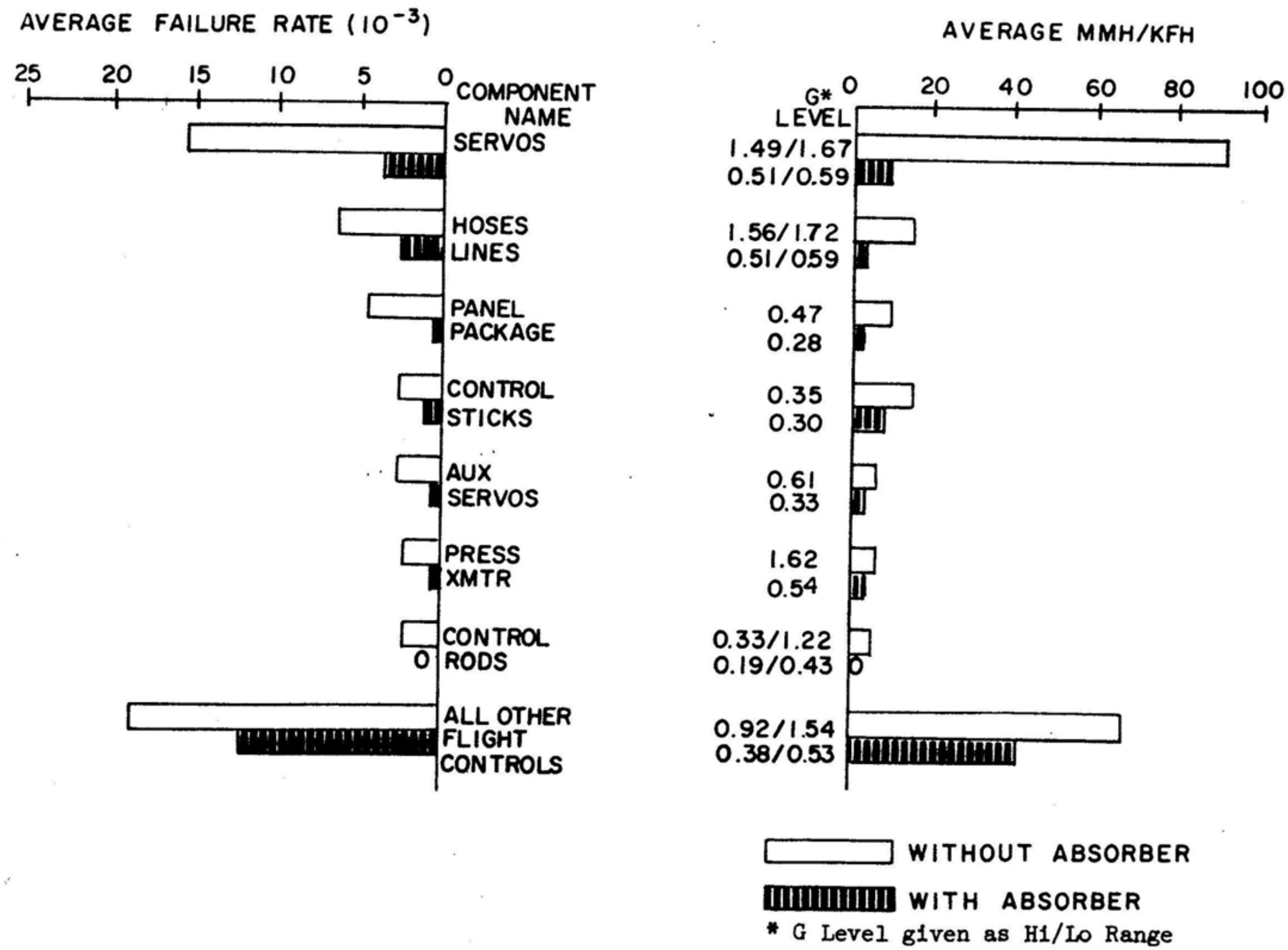
Comparison of Average Failure Rate and MMH/KFH for Selected Utility Subsystem Components.



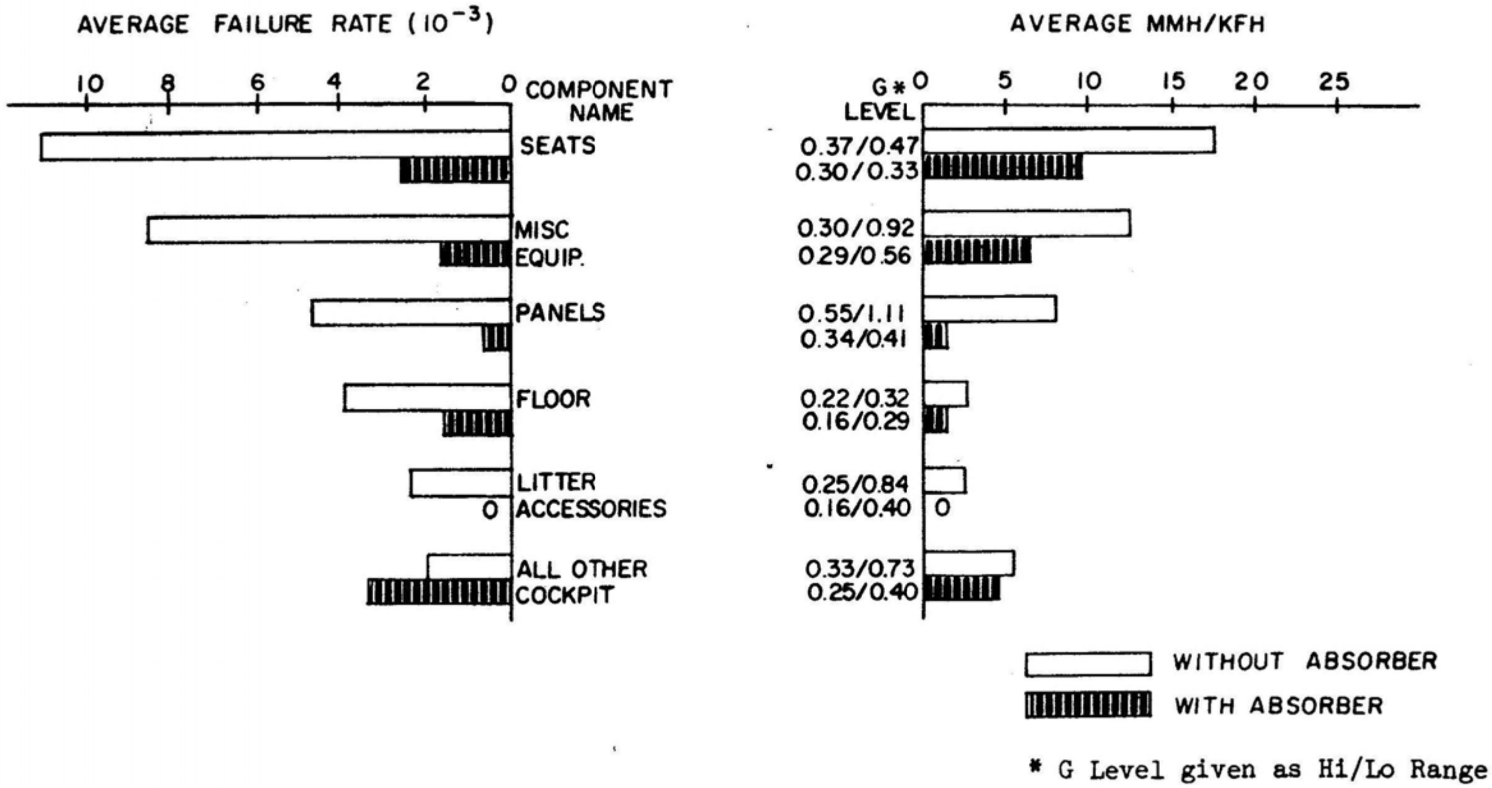
Comparison of Average Failure Rate and MMH/KFH
for Selected Landing Gear Subsystem Components.



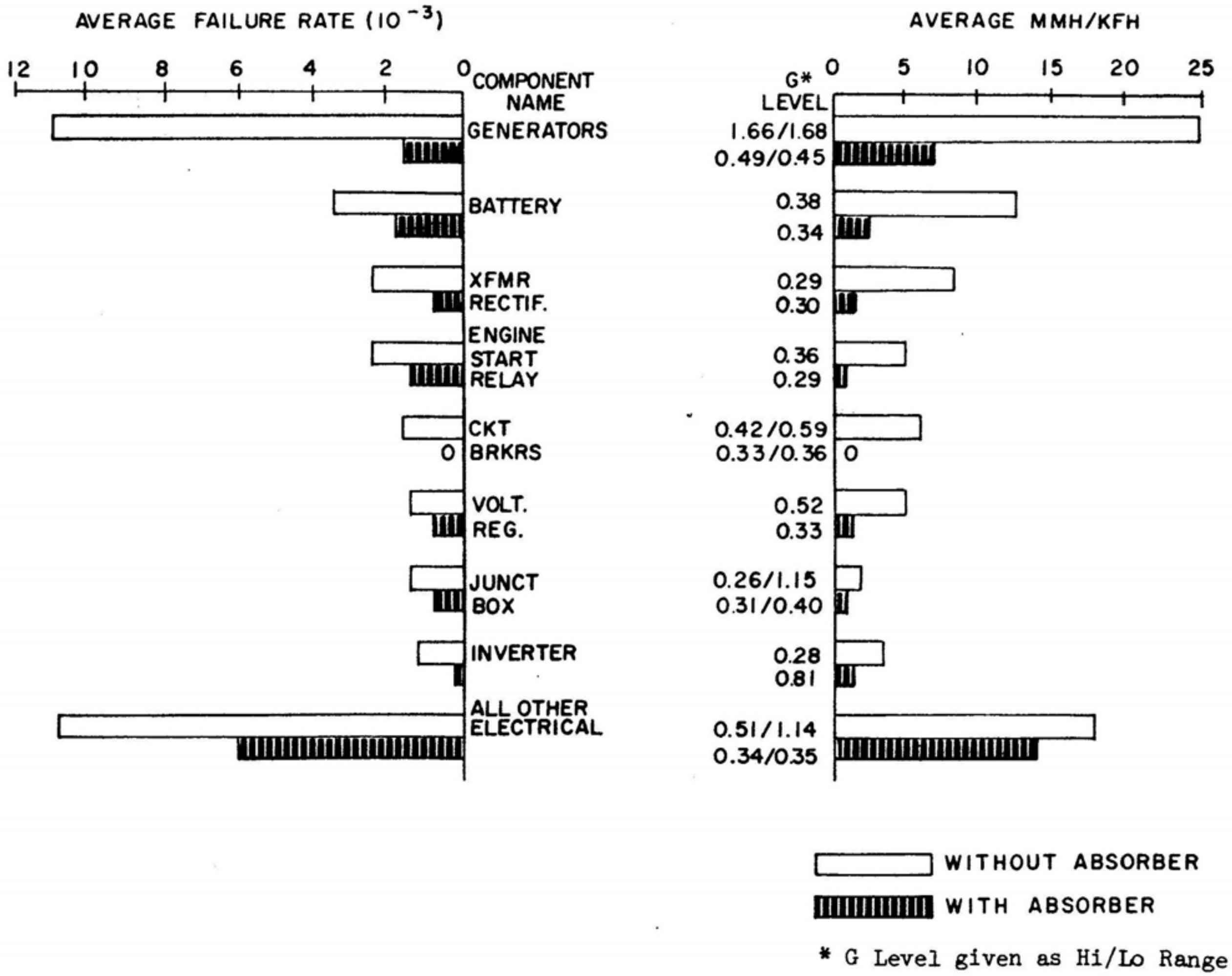
Comparison of Average Failure Rate and MMH/KFH for Selected Fuel Subsystem Components.



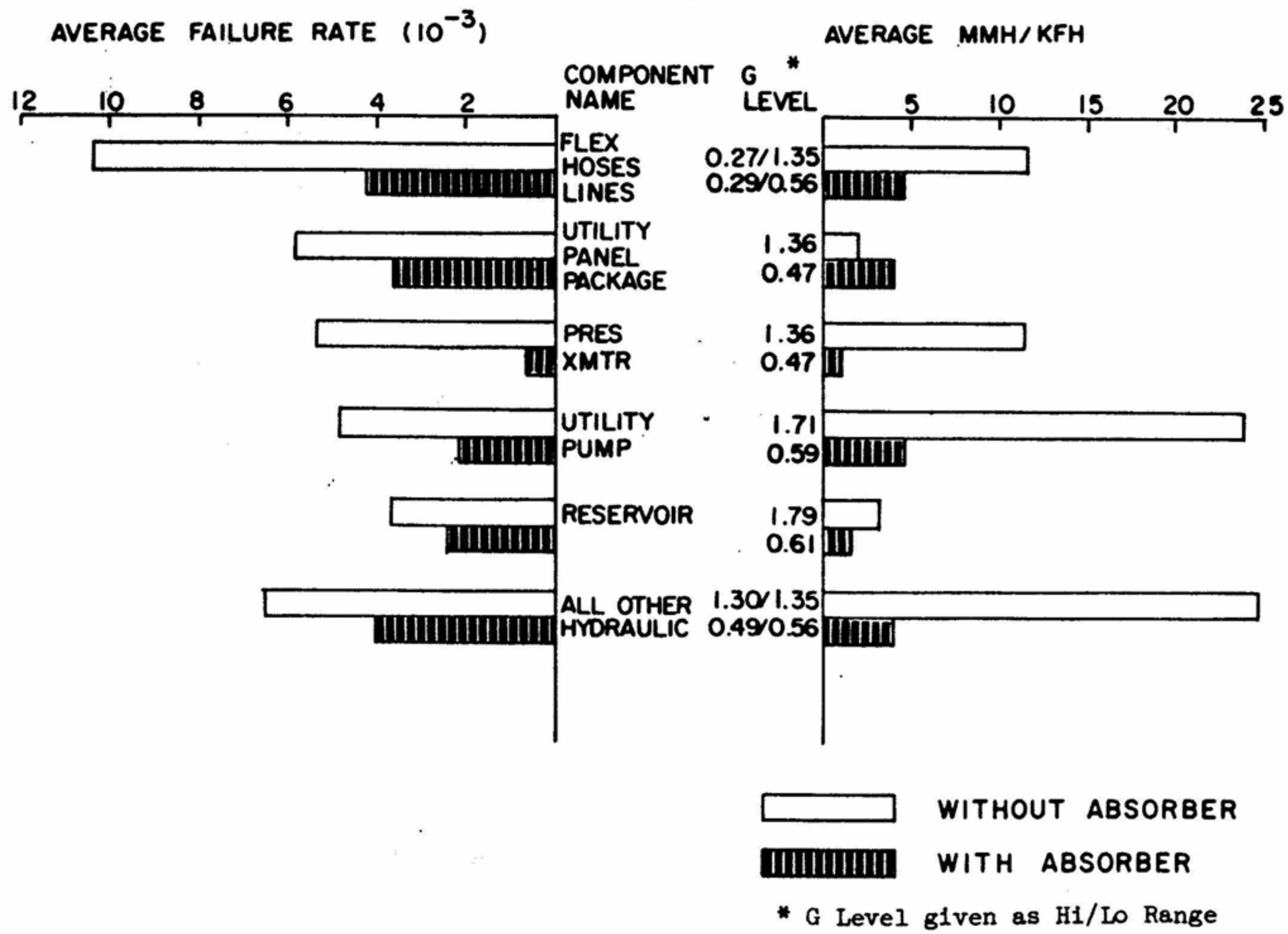
Comparison of Average Failure Rate and MMH/KFH for Selected Flight Control Subsystem Components.



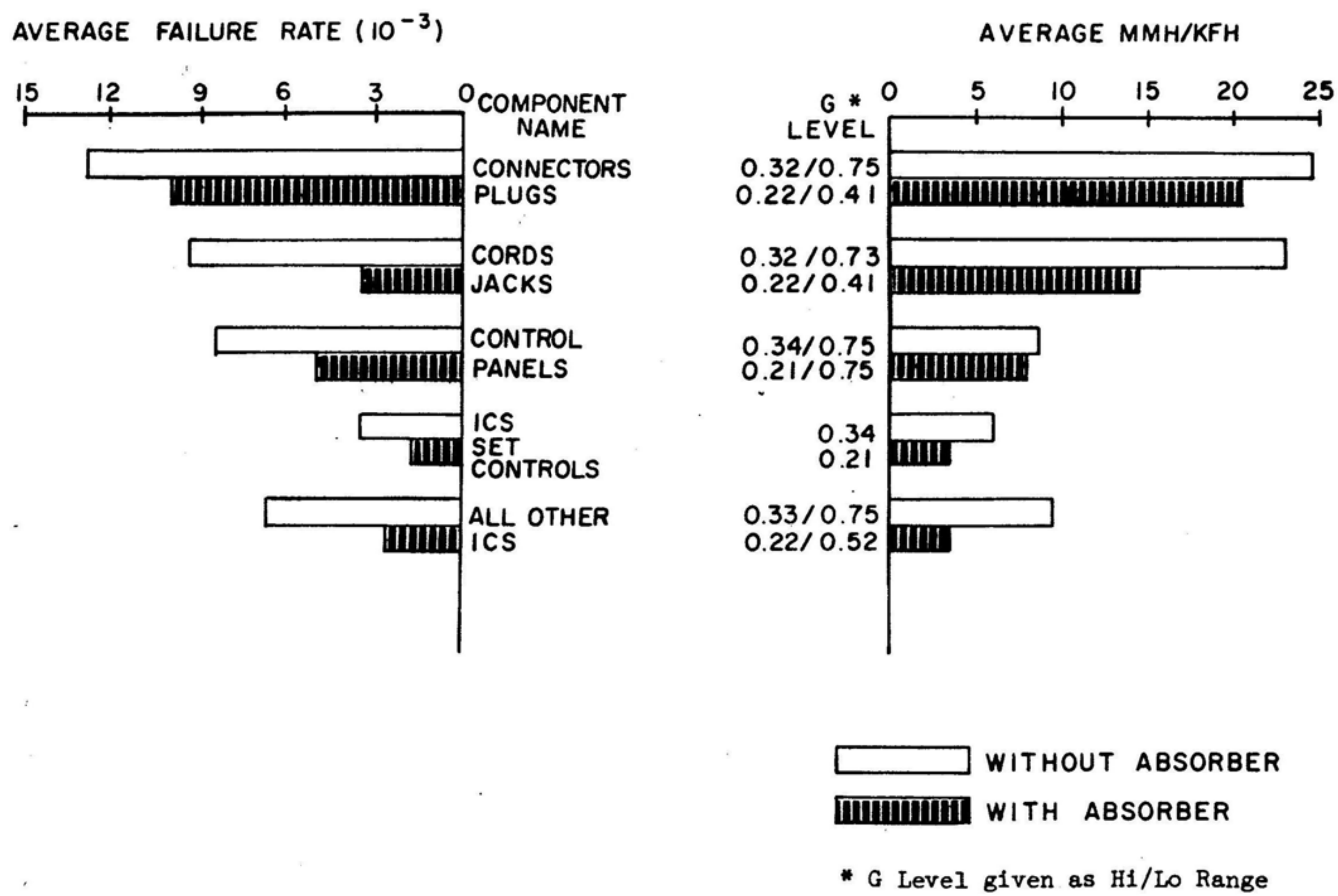
Comparison of Average Failure Rate and MMH/KFH for
Selected Cockpit/Fuselage Subsystem Components.



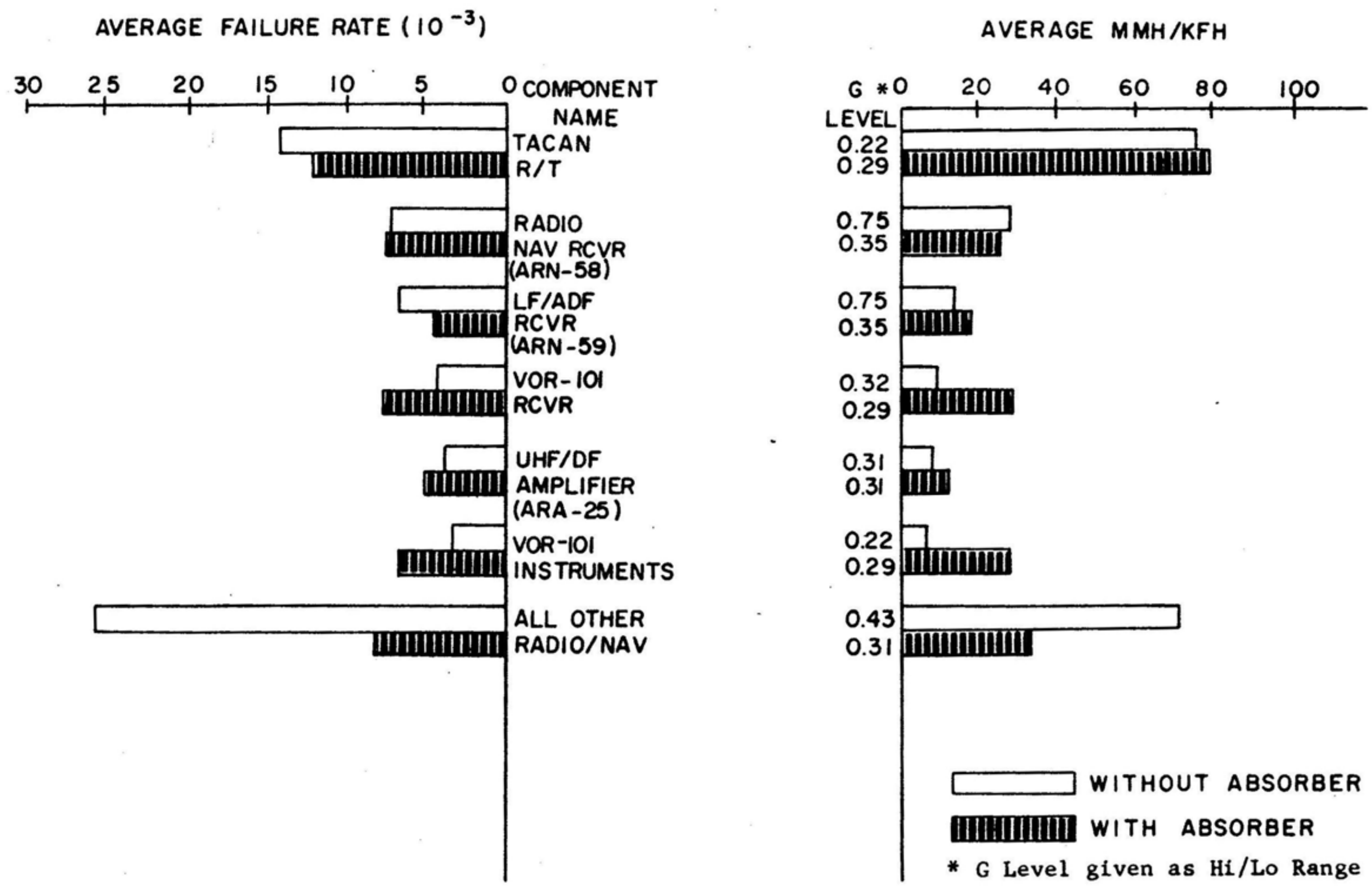
Comparison of Average Failure Rate and MMH/KFH for Selected Electrical Subsystem Components.



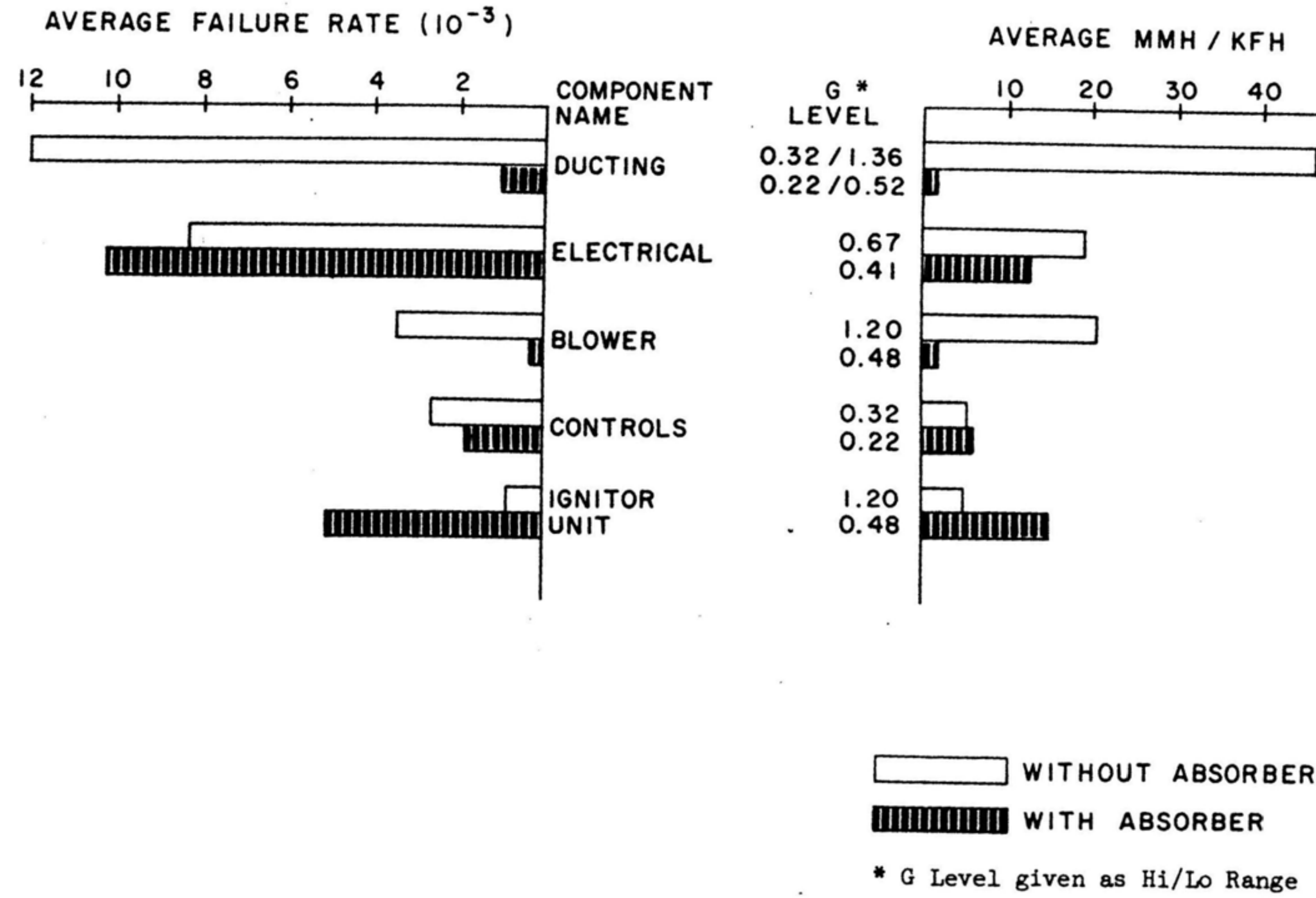
Comparison of Average Failure Rate and MMH/KFH for Selected Hydraulic Power Subsystem Components.



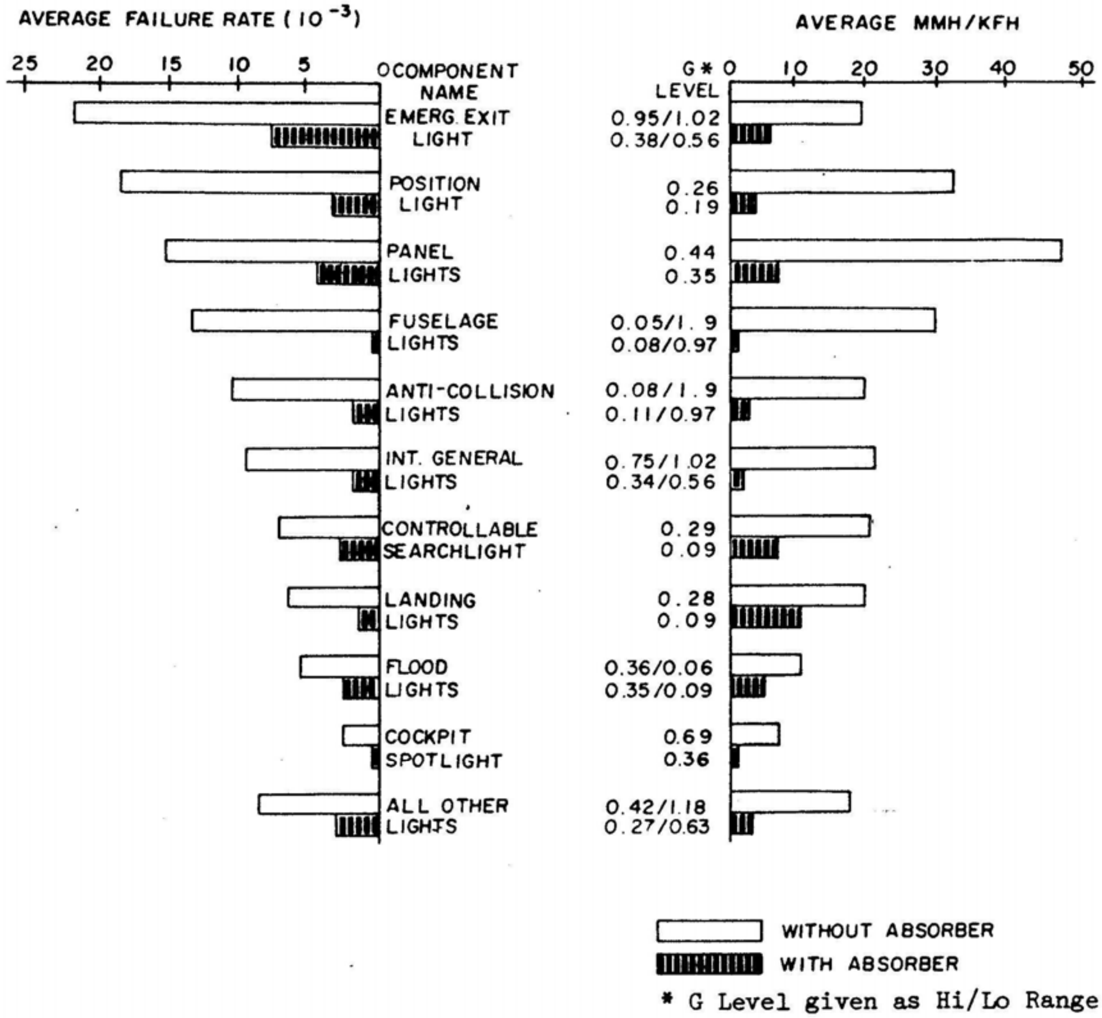
Comparison of Average Failure Rate and MMH/KFH for
Selected Intercommunications Subsystem Components.



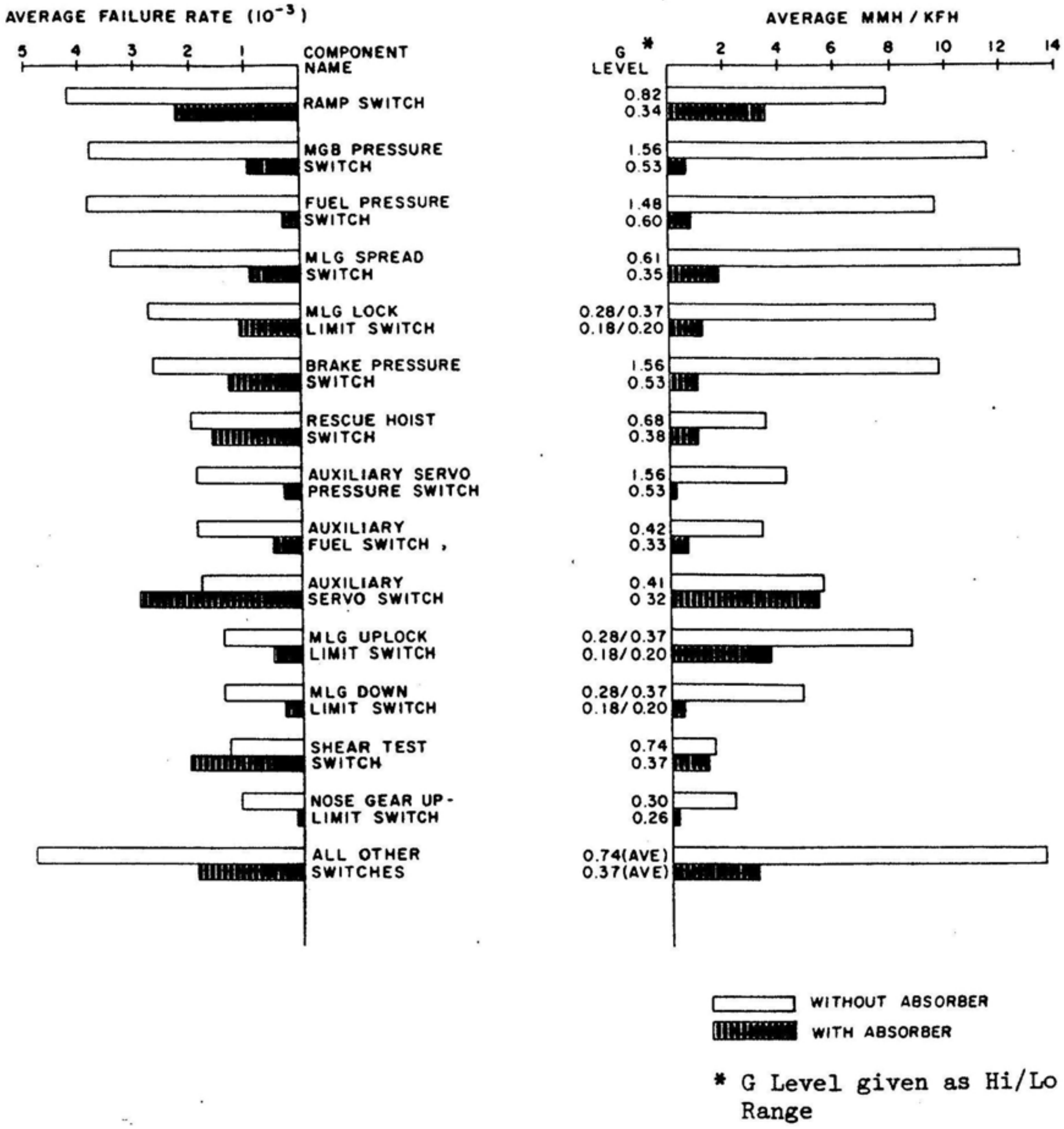
Comparison of Average Failure Rate and MMH/KFH for Selected Radio Navigation Subsystem Components.



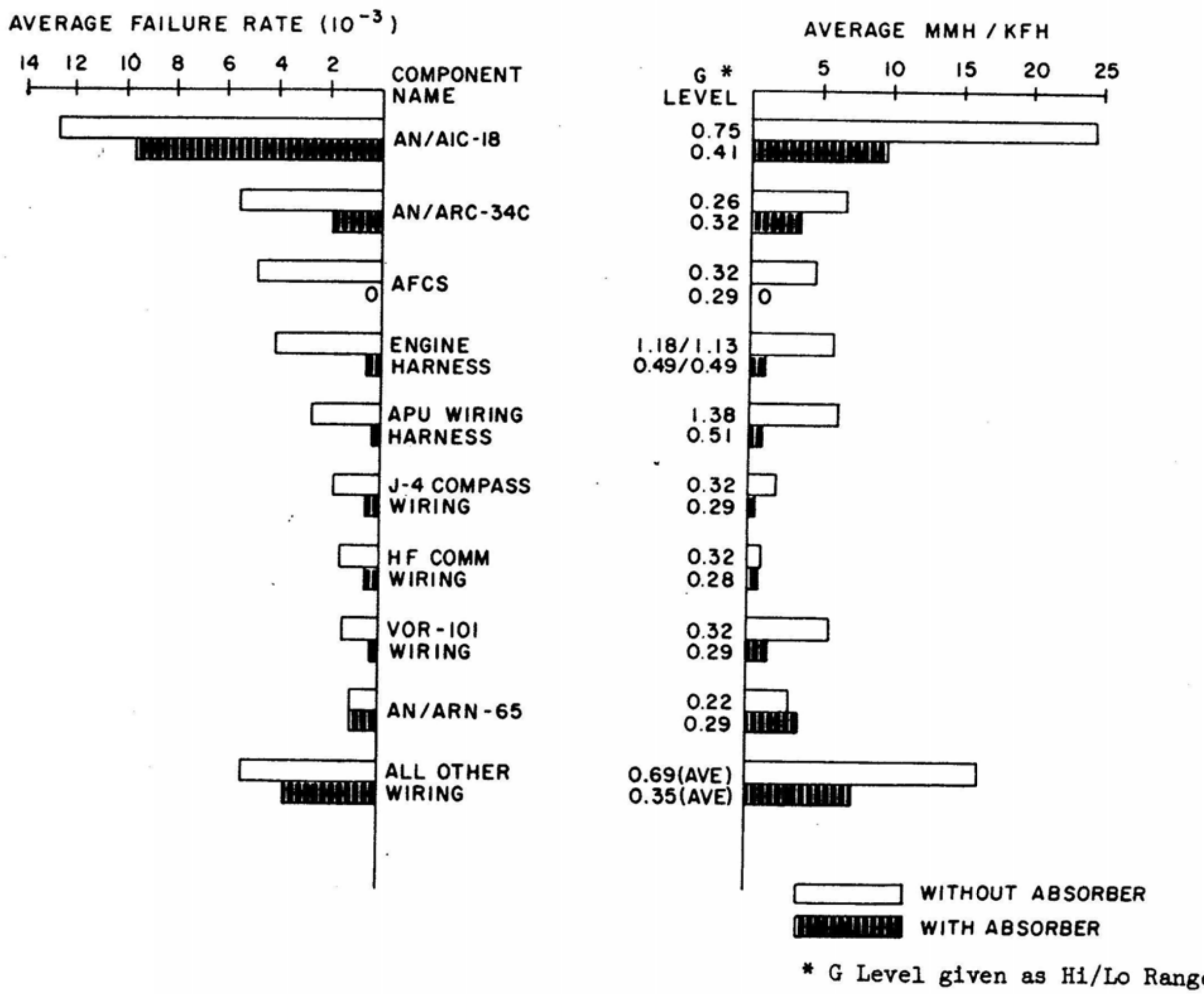
Comparison of Average Failure Rate and MMH/KFH for
Selected Airconditioning/Heating Subsystem Components.



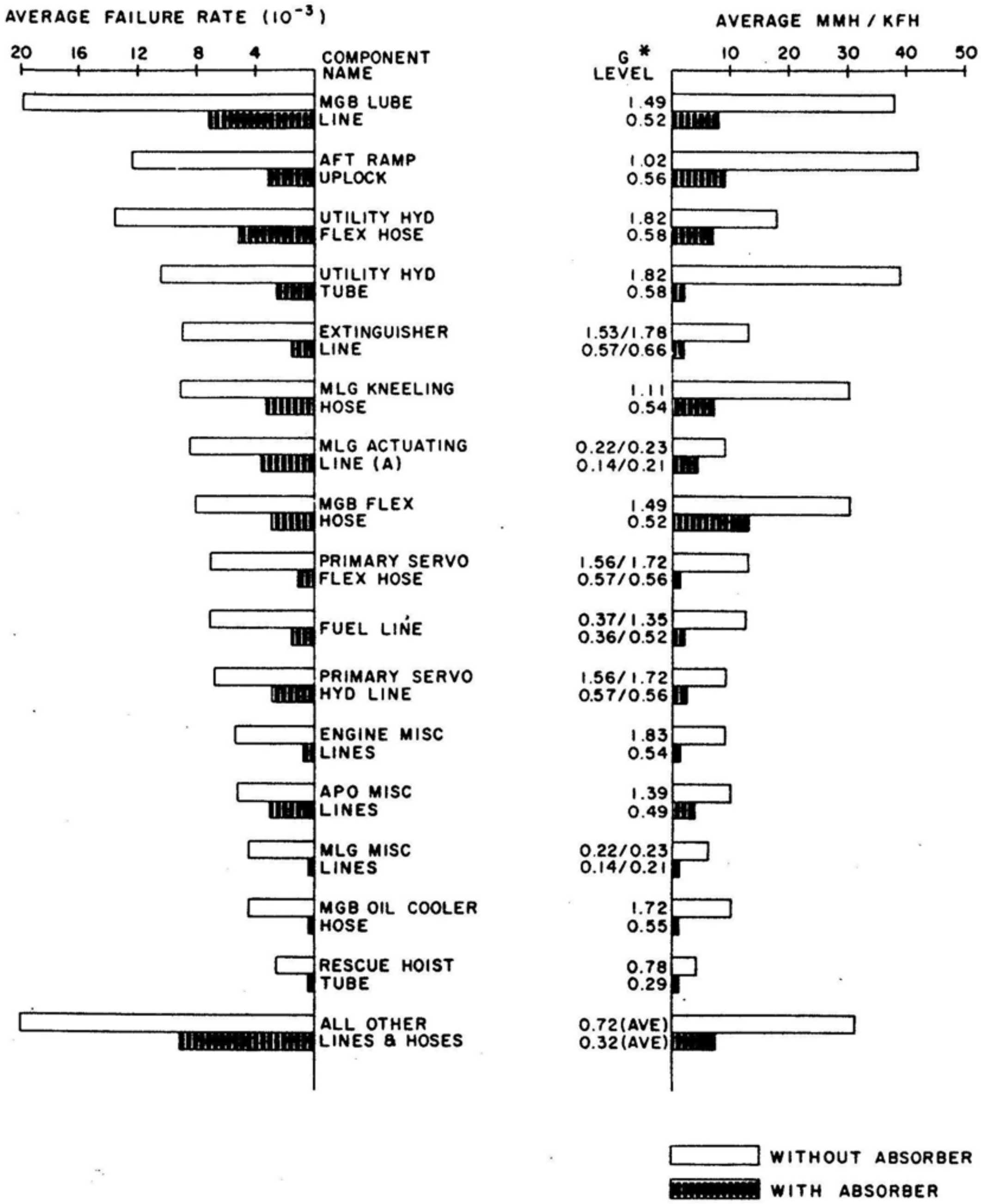
Comparison of Average Failure Rate and MMH/KFH for all Internal and External Lights.



Comparison of Average Failure Rate
and MMH/KFH for all Switches.

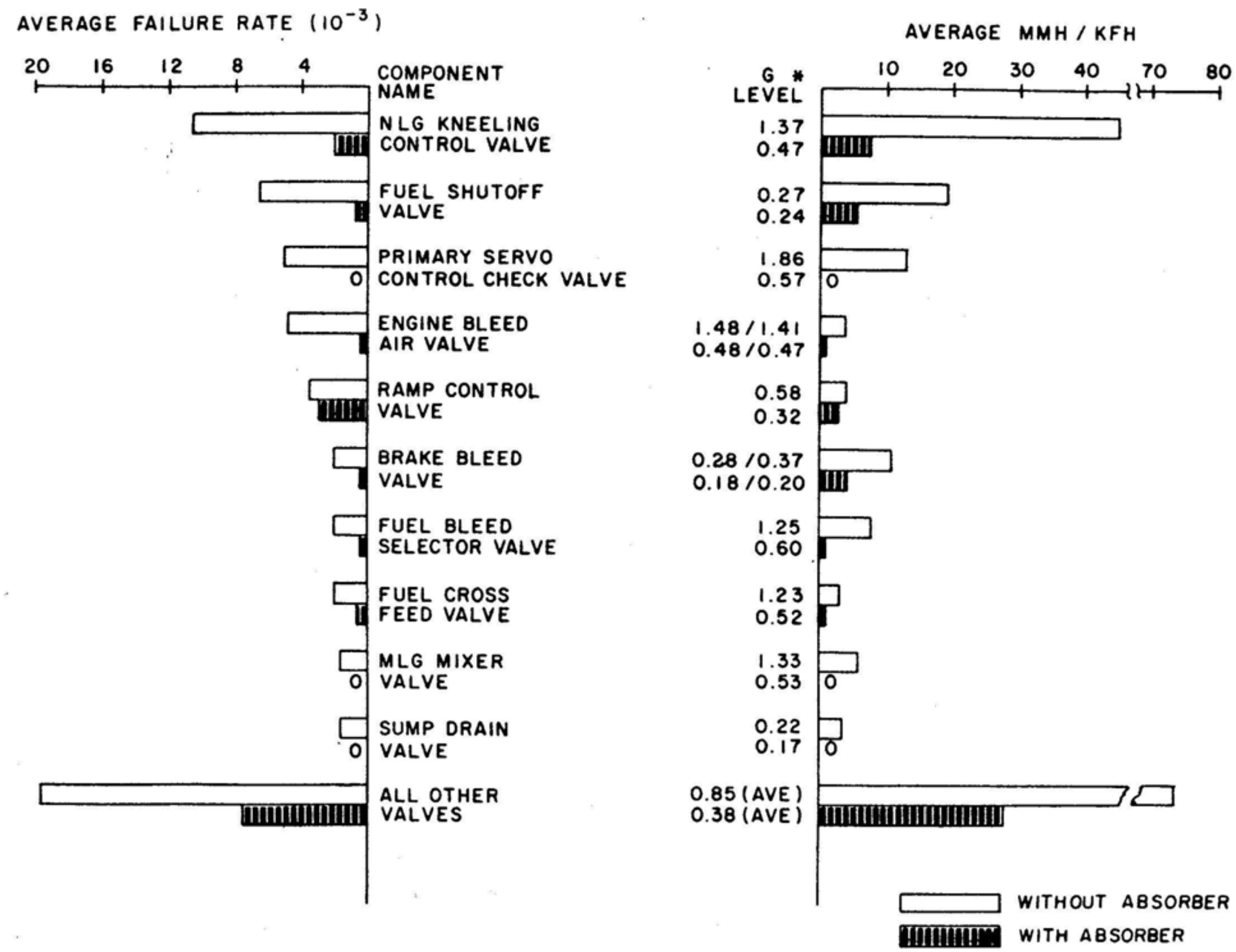


Comparison of Average Failure Rate and MMH/KFH for all Connectors/Plugs/Wiring.



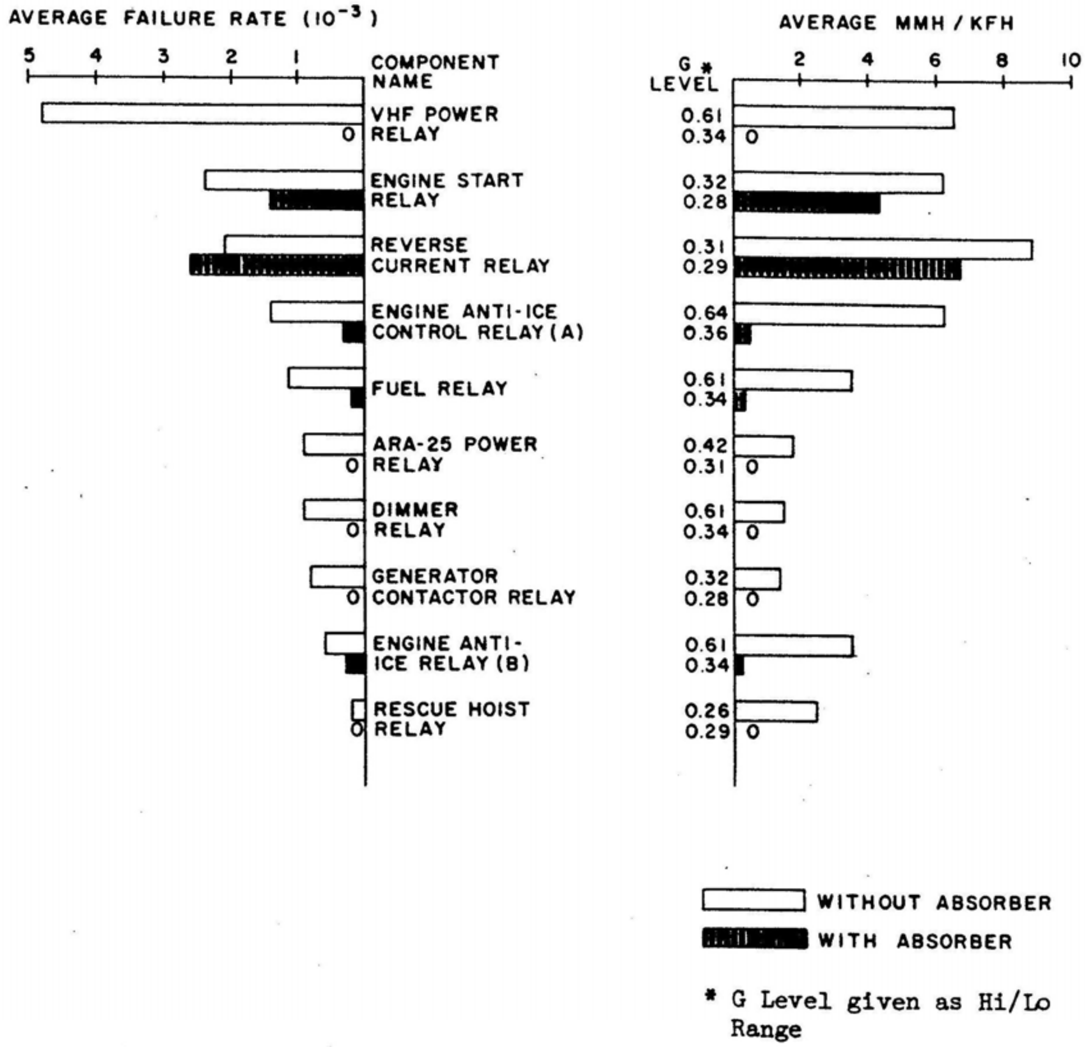
* G Level given as Hi/Lo Range

Comparison of Average Failure Rate and MMH/KFH for all Hoses and Lines.



* G Level given as Hi/Lo Range

Comparison of Average Failure Rate and MMH/KFH for all Valves.



Comparison of Average Failure Rate and MMH/KFH for all Relays.

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14. ABSTRACT

One routine maintenance item facing the helicopter industry today is the issue of rotor track and balance (RT&B). While the task of reducing vibrations is often overlooked as simply an unimportant "maintenance" concern, what should not be overlooked is the extensive amount of time and money committed by maintenance to smoothing an aircraft. If there were a way to make the process of rotor track and balance more efficient it would be a huge boost to the helicopter industry in both time and money. The first steps towards research into new and improved methods is to evaluate what is currently used in the field, determine if there is room for improvement and if so what can be improved. While each company may use a slightly different approach to correct the problem, each method has essentially the same objective— to reduce vibrations in the helicopter structure due to main and tail rotor rotation. This document reflects the findings of a study done to gather information and evaluate the different RT&B methods that currently exist, pinpointing the existing weaknesses in the process. In most all cases, a qualitative approach was used in determining problems and comparing current systems as the actual proprietary algorithms used by RT&B companies were unavailable.

15. SUBJECT TERMS

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